Natural oak regeneration in response to selective cutting

- Restoration of temperate deciduous woodlands on abandoned agricultural land in Scandinavia

Samuel Keith

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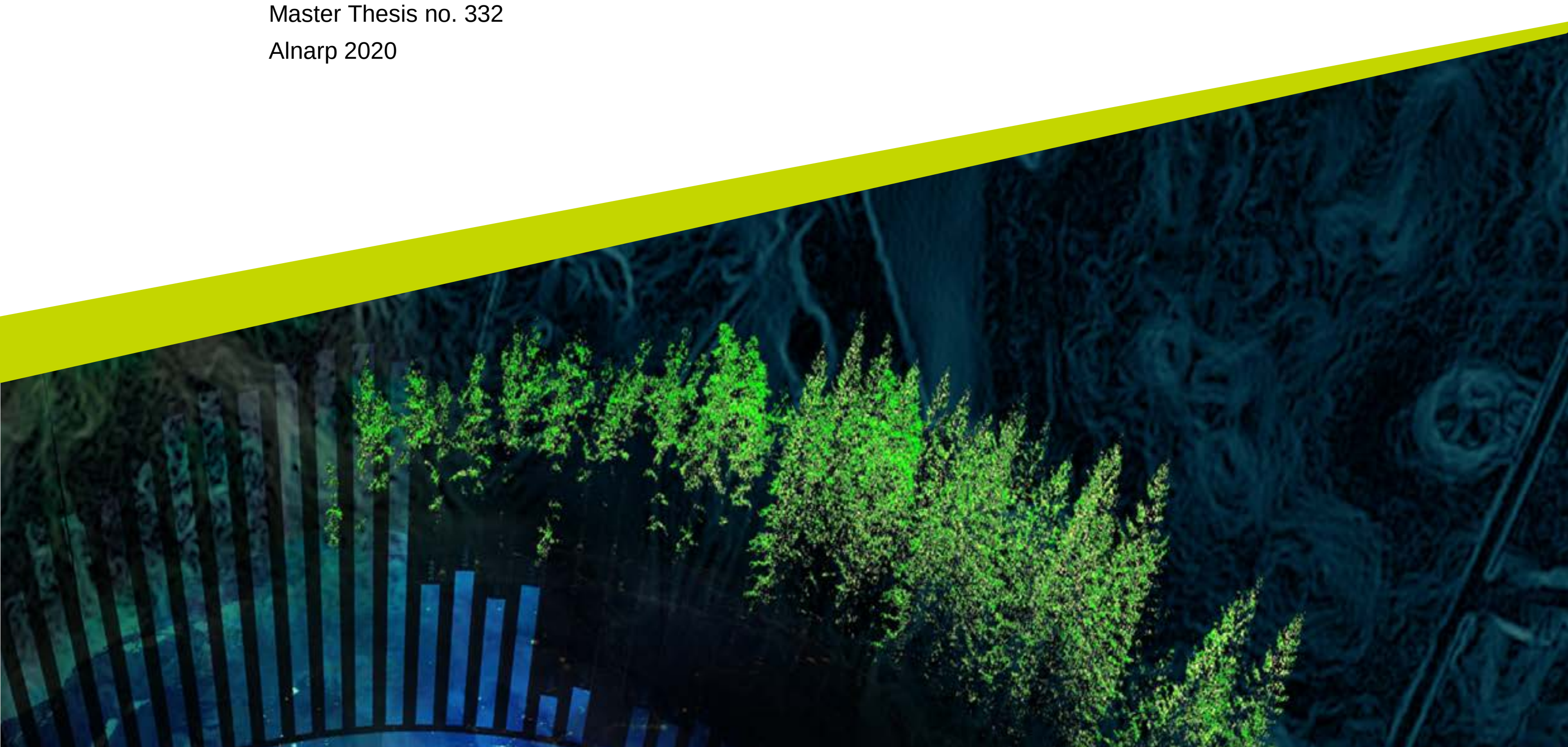

Natural oak regeneration in response to selective cutting – restoration of temperate deciduous woodland on abandoned agricultural land in Scandinavia.

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Abstract

The natural regeneration of sessile oak (*Quercus petraea* (Matt.) L.) and pedunculate oak (*Quercus robur* L.) is largely uncertain across central Europe and Scandinavia. Both species are key components of unique biodiversity niches, but have been supressed under modern forestry and land use practices. During the last century, large areas of semi-natural mixed forests have re-established on agricultural land abandoned from traditional farming, however these forests are often overgrown and form dark environments. Environmental schemes, such as the ‘TransForest’ project, have identified such areas as potential sites for the restoration of temperate deciduous woodland. Selective cutting is seen as a management option that can favour the natural regeneration of temperate broadleaf tree species such as oak which in the long run, contributes to the achievement of an array of biodiversity goals. The process of selective cutting is founded upon the principle that oak regenerates best in light rich environments and the targeted removal of shade dominant tree species e.g. Norway spruce, can contribute to the creation of lighter forest environments. This study analyses the effectiveness of selective cuttings on the natural regeneration of oak in a series of mixed forest stands across southern Sweden as well as the relationship between oak seedling density and light availability. The stem density of oak seedlings in different height classes is used as a response indicator to cuttings and hemispherical photographs have provided measurements of the understory light transmittance. The association between oak seedling density and light availability is found to be most significant for stems under 20 cm indicating that selective cuttings have had a positive impact on oak recruitment. The short time span of this experiment is suggested as a reason that improved regeneration is not yet realised in the taller height classes. Browsing by wild ungulates is also discussed as posing a significant threat to oak establishment and should be paid due consideration in restoration efforts.

Keywords: Light demanding species, selective cutting, restoration, ecosystem services, broadleaf dominated

Sammanfattning

Ek är en av de trädarter i Europa som hyser störst biologisk mångfald. I dagsläget står eken för en betydlig mindre andel av skogsarealen och volymen i Sverige jämfört med under 1600 -och 1700 talet. Både klimatförändringar och människans utbredning har haft påverkan på skogslandskapet och har tillsammans bidragit till minskningen av ek-dominerade skogar. Detta syns tydligt över hela landet. Det moderna svenska skogsbruket är grundat på ett system som gång på gång främst gynnar barrträd framför lövträd och vars målsättning är att öka ekonomiska värden. Intensiv markberedning, tät plantering av barrträd, och storskaliga avverkningar med korta omloppstider skapar en miljö där eken inte trivs. Dessutom saknas det i det svenska skogsbruket många naturliga störningar, processer och strukturer som ekens föryngring är beroende av. Ekplantor kräver tillgång till olika grader av solljus under olika livsfaser, men som art betecknas den oftast som ett ljusälskande trädslag och frekventa störningar som öppnar upp skogen under längre tid är avgörande. Från ett naturvårdsperspektiv finns en del åtgärder till hands som kan bidra till att få fram lövträd som ek, en av dessa är ett relativt nytt koncept som kallas för *naturvårdsgallringar* (eng: selective cuttings) och har förut visat en positiv påverkan på ekföryngring. Denna studie är baserad på en del av forskningen som ingår i ett större projekt '*TransForest*' vilket är ett samarbete emellan Sveriges Lantbruksuniversitet (SLU), Norsk Institution för Naturforskning (NINA) och ProNatura. Projektet har identifierat en mängd semi-naturliga blandskogar med ett stort inslag av ek, som har etablerats på före detta betesmark under det senaste århundradet. Under 2016 utfördes det en inventering av antal ekplantor i utvalda skogsbestånd i både Sverige och Norge och under samma år gallrades det bort bland annat gran och björk från dessa skogar. Under en uppföljning år 2019- har antalet ekplantor återinventerats samtidigt som en uppskattning av ljusinsläppet gjordes i både de gallrade och ogallrade bestånden. Analysen är fokuserad på en jämförelse av antal ekplantor mellan år och bestånd, och ljusinsläpp anses kunna vara en faktor som starkt kan påverka resultatet. Resultaten från denna studie visar att det finns tecken för att kunna se en positiv utveckling eftersom småplantorna (upp till 130 cm) har ökat i gallrade bestånd jämfört med i kontrolytorna. Förklaringar till den svagare än förväntade responsen i föryngringen skulle kunna vara ett högt betestryck som är karakteristiskt för södra Sverige. Klövviltsstammen har ökat kraftigt under samma tidsperiod som ekens tillbakagång och det finns starka bevis för att vilt (bland annat rådjur och dovhjort) håller ek som en favorit bland födokällor. Om betestrycket är tillräckligt högt är det omöjligt för eken att komma undan och den kan därför bli utkonkurrerad av andra trädslag så som till exempel asp, avenbok, björk och gran. Det är viktigt att skötselplaner förtydligar önskemålen som finns bland olika aktörer. Är det först och främst att eken ska gynnas behövs det antigen större störningar eller att försvara ekplantor med stängsel. Under vissa omständigheter är det kanske inte ekens bevarande som bör vara i fokus, utan istället andra arter med höga naturvärden

Keywords: Naturvårdsgallringar, skogsskötsel, ekosystemtjänster

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1. Introduction

A short history of oak in the landscape

On a global scale, forest environments are subject to exploitation, degradation and deforestation. In northern and central Europe, the forest history is scarred by a substantial decline in the abundance of deciduous dominated woodlands. Of particular interest in this study, the oak genus (*Quercus*) is amongst one of the most important species that has been affected in the region. The pedunculate oak (*Quercus robur* L.) and sessile oak (*Quercus petraea* (Matt.) L.) have seen a drastic reduction of their share of pollen abundance in records since the Holocene (Foster & Lindbladh 2010). The demise is attributed of course, to fluctuations in climate change as well as an underlying relationship with anthropogenic activity during the last 300 years (Foster & Lindbladh 2010). The exploitation of oak can be seen as starting as far back as during the 16th century when oak timber was used extensively as both a valued source of sawn timber for peasants and for the construction of Royal naval fleets. Thereafter, oak woodlands continued to diminish and have since been systematically removed from the landscape by widescale clearance in order to create space for expanding agricultural land, with the occasional retention of individual trees used as a fodder source for animal husbandry (Eliasson 2002; Brunet 2006).

In Sweden, oak currently shares approximately 1-2% of the forest standing volume (Skogskunskap 2018) almost all of which is confined to the south where the climate is more hospitable. A fraction of what it once was, the remaining oak woodlands are a patchwork of small disconnected clusters in the matrix of the modern Scandinavian landscape which is dominated by urban sprawl, agriculture and intensively managed production forest plantations (Halme et al. 2013). Large old-growth oaks are usually represented as individual trees retained on estate infields or as pockets of natural oak woodlands in an otherwise conifer dominated forest landscape (Eliasson & Nilsson 2002). In Scandinavia, the most predominant oak mixtures are with Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), and Birch (*Betula spp.*), such forests types share common management regimes of mechanical site preparation, dense planting, thinning practices and clear felling with a short rotation period of 40 to 120 years (Drössler et al. 2012; Halme et al. 2013) were the main objectives are often focused towards maximising economical gains. Considered a species that can dominate in light rich environments, oak has limited regeneration success and progresses rarely into the overstory in closed canopy environments or on fertile soils that are void of natural disturbances (Anninghöfer et al. 2015; Vera 2000). In other words, oak regeneration and seedling establishment is presumed most successful in forest types that are subject to a range of gap creating disturbance regimes which in turn maintain large proportions of incoming sunlight that reaches the forest understory.

Natural disturbances such as fire and grazing by large herbivores which once maintained a transitional landscape from grassland savannahs to open-canopy light-rich forests are now largely absent from European plantation forests (Vera 2000; Jensen et al. 2012). Silvicultural practices that seek to replicate natural gap creating processes and re-open forests offer a glimmer of hope for natural oak regeneration (Bobiec et al. 2011; Bobiec et al. 2018; Brunet et al. 2014; Götmark & Kiffer 2014; Jensen et al. 2012; Mölder et al. 2019; Spînu et al. 2020). Where these gap creating processes are neglected, oak is not only outcompeted by Norway spruce and Scots pine but also other more shade tolerant broadleaf species namely; European beech (*Fagus sylvatica*), Lime (*Tilia spp.*) and Hornbeam (*Carpinus betula*) (Churski et al. 2017). The intensification and mechanisation of forestry practices has replaced woodland pasture and slash-and-burn cultivation with arable and pastoral farmland as well as highly productive monoculture plantations aimed at supporting a growing timber industry (Brunet 2006; Foster & Lindbladh 2010). In turn, the refinement of plantation stands has led to the progressive darkening of forest environments through narrow and regimental spacing that maximises productivity. This has severely inhibited the successful regeneration of light demanding and disturbance dependent vegetation to such an extent that their future existence within the landscape is threatened (Petersson et al. 2019a). In order to satisfy production goals and other aspects of forest multi-functionality, it can be considered that silvicultural practices need to be continually adapted to weigh in favour of species, such as oak that are otherwise neglected in modern forestry (Löf et al. 2016).

Ecological obstacles for oak regeneration

A range of external factors act throughout the different stages of oak establishment that combined, reduce the probability of a successful regeneration (Madsen & Löf 2005). Large, energy packed acorns are designed to give sprouting seedlings a head start over competing vegetation but are however also prone to predation from granivorous rodents. When rodent populations are high, predation on acorns prior to germination can be so severe that a successful regeneration is prohibited (Birkedal et al. 2010). In Scandinavia therefore, during stand establishment, direct planting of bare-rooted seedlings is often chosen over sowing acorns as the favourable regeneration alternative (Löf et al. 2012; Leverkus et al. 2015) as an attempt to minimise economic loss.

In the stages following germination, resource competition (namely for; light, water, and nutrients) becomes a key decider of oak seedling survival. Dense ground vegetation cover such as grasses that are fast to establish can reduce the water availability and substantially inhibit development of an oak seedlings root system during early growth (Collet et al. 2006). Subsequently the presence of grasses and other such densely growing ground vegetation provides cover for rodents which may further increase the risk of seedling damage. In oak plantations, mechanical site preparation accompanied by shelterwoods are the most usual approaches used to combat the extent of ground vegetation. However, reducing the presence of grasses may also serve to increase the survival rate of other competitive species such as birch (Nilsson et al.1996; Löf et al. 2012) and therefore counteracting the intended purpose of promoting oak. Such methods are not always suitable in existing mixed forests that instead utilise manual labour. In European mixed forests, oaks are amongst the most heavily browsed of all tree species and are often favoured over other tree species by; moose (*Alces alces* L.), roe deer (*Capreolus capreolus* L.), fallow deer (*Dama dama* L.) and red deer *(Cervus elaphus* L.) (Bergquist et al. 2009; Götmark et al. 2005; Leonardsson et al. 2015). Oak seedlings depend therefore on a fine balance between of the presence of ground vegetation and woody vegetation that offers adequate protection against browsing, but not significant enough to stunt their growth (Jensen et al. 2012). The height growth of both oak seedlings and re-sprouting oak shoots is negatively associated with higher levels of browsing from deer and moose (Mårell et al. 2018) with the intensity of browsing increasing as soon as the seedlings reach above the surrounding vegetation. The browsing pressure is so great that fencing is considered necessary to ensure a successful oak understory (Bergquist et al. 2009; Jensen et al. 2012).

Distribution of oak

Within Europe, the natural stronghold of both oak species overlaps considerably (Figure 1 and Figure 2), and they are often found growing side by side. Generally, their ranges stretch throughout Europe from the British Isles in the west across to eastern Europe and from southern Scandinavia to northern Italy and Spain in the south (Savill 2019). The southern limit is difficult to identify as both can form natural hybrids with more southern oak species e.g. Hungarian oak (*Quercus frainetto*) (Curtu et al. 2009). Pedunculate oak has a somewhat wider range stretching even to the Ural Mountains in Russia, encompassing the distribution of sessile oak.

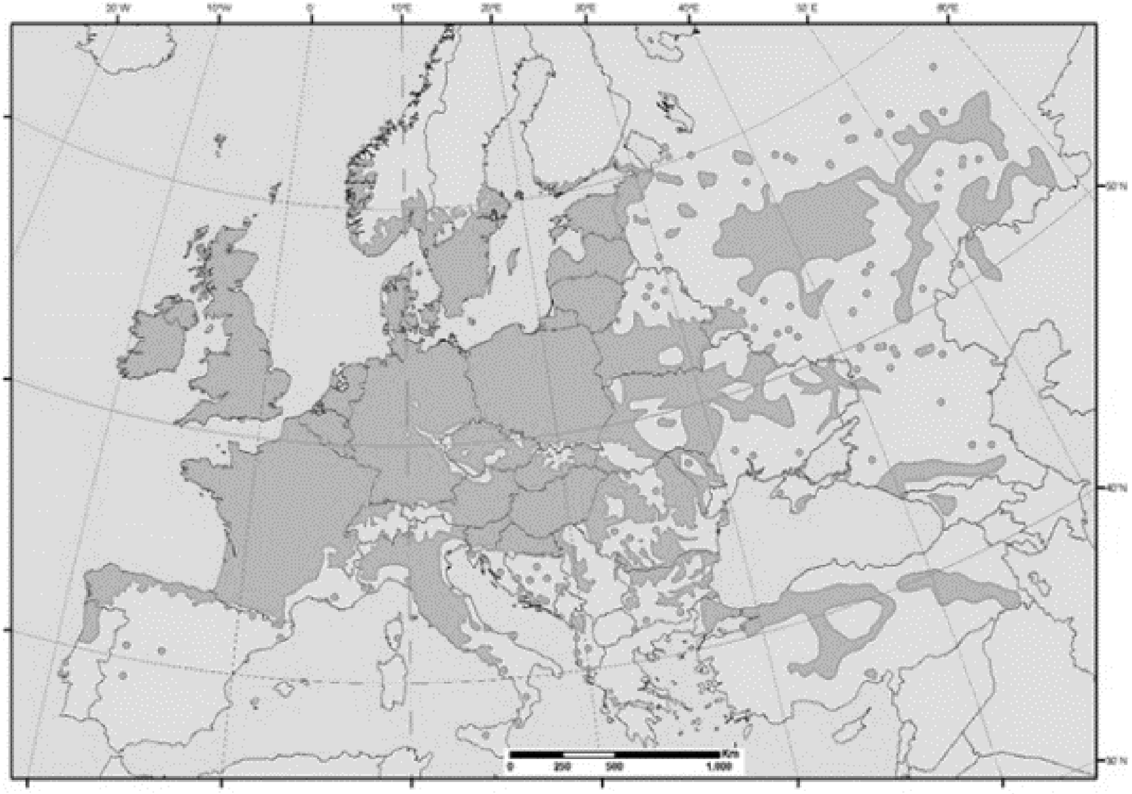

Figure 1. *The distribution of Q. robur across central and northern Europe.*

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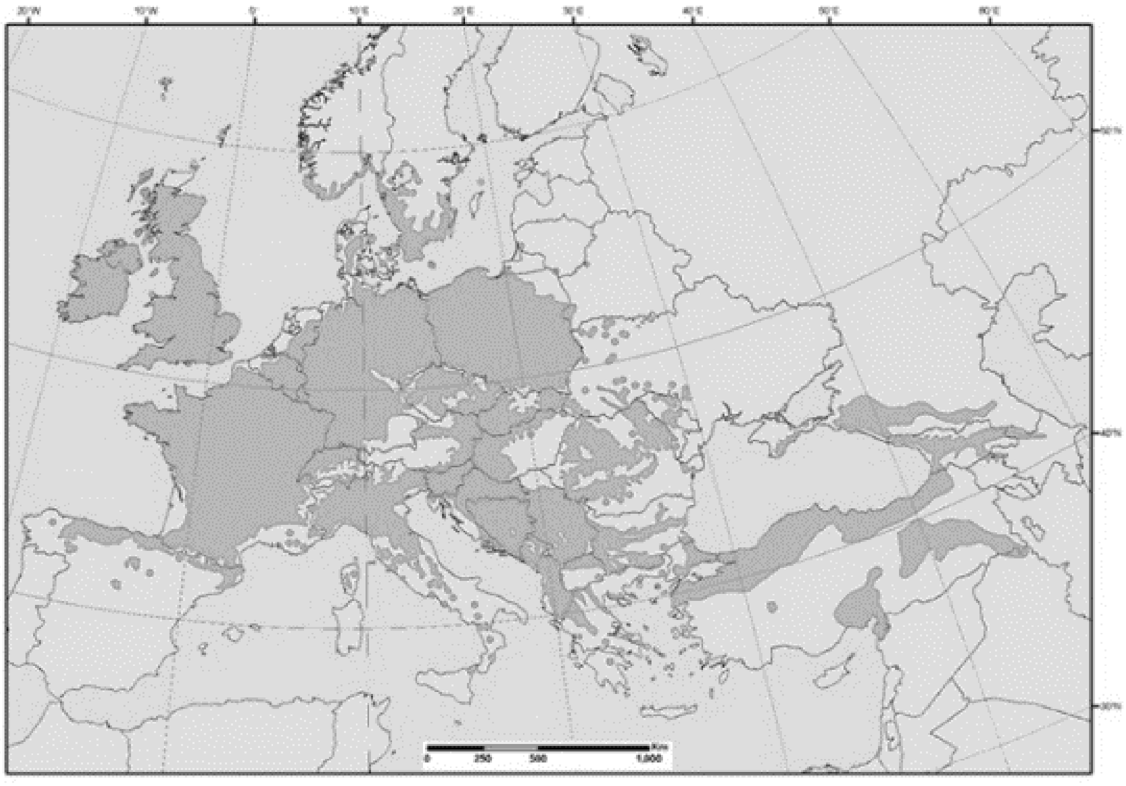

Figure 2. *The distribution of Q. petraea across central and northern Europe.*

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Opportunity for the restoration of oak habitats

The growing number of government-backed conservation orientated management schemes can be seen as a response to an increased public awareness and appreciation of forest and woodland derived ecosystem services. Projects such as '*TransForest*' and the '*Swedish Oak project*' exist as a means to support the conservation of biodiversity through preservation and management of mixed broadleaf and oak dominated ecosystems. As an alternative to focusing entirely upon maximal economic gain, conservation orientated management can help to enrich the quality of forest ecosystems through tree species regulation and creation / maintenance of structural variance (Götmark 2007). Components such as snags, standing dead wood, old growth trees and natural oak regeneration for example are neglected in current forestry systems (Götmark 2013; Löf et al. 2016). Selective cutting and targeted removal of shade tolerant conifers together with the preservation of old growth structures and deadwood in mixed forests is considered here as one important step in the direction of ecosystem support management.

Forest restoration can come in many forms, Stanturf et al. (2001) classify different restorative measures into strategies such as 'rehabilitation, reconstruction, reclamation, and replacement'. The most appropriate restorative strategy to be implemented depends upon; the initial state of an ecosystem, the desired point of recovery, as well as temporal, spatial and economic constraints. From a financial perspective, the more degraded the system, the more expensive the restoration becomes (Chazdon 2008; Stanturf et al. 2014; Löf et al. 2019). In large parts of Scandinavia, a part of the expansion in total forest area during the last century is due to natural establishment on unused marginal agricultural land. Change in land use practices during this period has resulted in large areas being abandoned from traditional farming. For instance, between 1949 and 2009, 95% of dairy farms closed in Norway and 80% of farms in general were lost (Bryn et al. 2013). This has substantially contributed to land area that has the potential for afforestation purposes. In a recent related study, Norden et al. (2019) estimated the total area of abandoned farmland in Sweden and Norway that is currently occupied by mixed forests and suitable for restoration to be over 100,000 hectares. Non-productive agricultural lands are an untapped resource in the fight to restore ecosystem functionality, whether it be rehabilitation of species composition via conversion or transformation (Zerbe 2002; Pommerening 2004) or reconstructing native plant communities on reclaimed land (Stanturf et al. 2001; Chazdon 2008).

Establishment of mixed oak stands on marginal farmland could be an effective method of increasing the proportional share of broadleaved forests through reclamation. An active approach to stand establishment would include site preparation, direct seeding/planting and fencing, which are considered to be amongst the highest costs involved in oak regeneration (Bullard et al. 1992; Löf & Birkedal 2009). Recent research into direct seeding of acorns suggests a more cost-effective alternative despite having an unpredictable outcome due to heavy acorn predation from rodents (Madsen & Löf 2005; Löf et al. 2019). There is also growing interest in developing more cost effective and passive restoration alternatives. Such methods are focused towards existing patches of forest on abandoned farmland that have already overcome the establishment phase and focus more precisely on restoring species compositions through the promotion of natural regeneration of valued broadleaved species, as oak. In such situations a key factor influencing survival of oak seedlings is the battle for sunlight against competition from shade-tolerant vegetation. In the temperate forests of Białowieża National Park for instance, hornbeam and lime are so prolific (Bobiec et al. 2011) that they outcompete oak seedlings in almost all cases. Even though oaks (especially sessile oak) are considered to have considerable re-sprouting ability, both hornbeam and lime are superior 'sprouters' (Matula et al. 2012). Over-competition therefore inhibits the ability of browsed oak saplings to capitalise upon available light at the forest floor level (Petersson et al. 2020). Selective cutting may be a solution to increase the understory light availability in mixed forests and relieve oak seedlings. Also called 'restoration cutting, release cutting, rehabilitation or conservation-orientated thinnings' (Leonardsson et al. 2015; Brudvig & Asbjörnsen 2007; Norden et al. 2019) the common goal is to improve the natural regeneration of oak by reducing canopy density and hence, increasing light transmittance to which oak seedlings are expected to respond positively to. In many cases, this involves the targeted removal of Norway spruce but also other woody vegetation such as birch and hazel. Previous studies have confirmed that opening up the canopy to increase light radiance in the understory can significantly improve both the height growth and diameter growth of oak seedlings, as well as its survival when compared with seedlings in dense closed canopy forests (Löf et al. 2007). Furthermore, oak is known to have substantial sprouting ability following top kill (Leonardsson & Götmark 2015) and an enhanced sprouting capacity has been linked to high light environments (Petersson et al. 2019b). Selective cuttings may therefore be a way to alleviate the long-term damaging effects of browsing upon oak regeneration by increasing light availability which would be expected to positively affect the sprouting capacity, and therefore survival of oak stems. However, there is little guarantee that increasing understory light levels will only serve to benefit oak seedlings. Many other broadleaves as well as Norway spruce also show strong light-growth relationships, so the effect may be two-fold (Götmark 2007; Löf et al. 2007).

Study aims

The main purpose of the study is to evaluate the response of natural oak regeneration to a series of selective cuttings in mixed forests. Secondly, effort is made to analyse the relationship between oak seedling density and the percentage of sunlight reaching the forest understory.

Upon the collected data, the following research questions are posed;

- Has selective cutting improved natural oak regeneration?
- Is the density of oak seedlings positively associated to light availability?
- Is there a clear correlation between basal area and light availability?

2. Materials and methodology

Study area and sites

In 2016 as part of the TransForest project a series of sites were established across Southern Sweden and Norway. This study makes use of a total of 18 of those sites (see Figure 3 and Table1). The chosen locations are mixed forests that have established on abandoned agricultural land during the last century. The mean forest age is between 40 – 80 years and the most common former land use in these areas has been pasture and/or meadows, which are considered suitable candidates for restoration (Benjamin et al. 2004; Stanturf et al. 2014). The prevailing mixture of broadleaf and conifers have together formed a closed canopy with a well-established understory of woody vegetation.

At the beginning of the experiment, temperate broadleaf species (*Quercus, Tilia, Fraxinus, Ulmus)* accounted for 44% of the mean basal area whilst other broadleaves and conifers made up 32% and 24% respectively. Norway spruce was the most prevalent conifer occupying at most 35% of the basal area in 2016 (Remmene, Västra Götaland). As for oak, the average share per site was 24%, with Bosnäs having amongst the most oak at 50% of basal area.

There is little to no sign of active silvicultural management within the forests. Apart from some firewood extraction, the lack of intervention has allowed the formation of a closed canopy at all sites (Norden et al. 2019) which was a desirable starting point for the experiment. Only at a handful of locations are there fences that divide boundaries between forest and grazed pastures, otherwise none of the sites or subplots have been specifically fenced to prevent browsing from wild ungulates.

Figure 3. Site locations; ***(1)*** *Aplared* ***(2)*** *Aspanäs* ***(3)*** *Bosnäs* ***(4)*** *Hovetorp* ***(5)*** *Klockaretorpet* ***(6)*** *Kvarntorp* ***(7)*** *Motala* ***(8)*** *Remmene* ***(9)*** *Slaka* ***(10)*** *Stöpen* ***(11)*** *Tullgarn (12) Tvärsjönäs* ***(13)*** *Berg* ***(14)*** *Håkås* ***(15)*** *Karljohans-vern* ***(16)*** *Kåpe* ***(17)*** *Sand* ***(18)*** *Svartskog*

Experimental design

In 2016 two distinct one-hectare (ha) plots were marked out at all site locations. One plot represents a control plot (C) – in which no cuttings were made, and the second plot represents the treatment plot (T) where selective cutting was carried out. Where the terrain and forest layout permitted, the plots where established in a square format (100 x 100m) and relatively close to each other as considered reasonable to aid practicality of future inventories (Figure 4). In locations where the terrain was non-ideal the plot shape was adjusted accordingly to maintain an area as close as possible to 1 ha. Prior to the selective cuttings, both the basal area and the basal area species share for each plot were measured, an estimation of the percentage share of oak in the overstory is presented in Table 1 alongside the three species with the highest basal area share per site.

In the same year approximately one-fourth of the basal area was removed from each treatment plot by selective cutting, either by chainsaw and tractor or harvester and forwarder (Norden et al. 2019). Selective cutting involved the targeted removal of conifers (mostly Norway spruce) and coarse woody vegetation (mostly hazel) as well as denser patches of birch. All oaks were maintained to provide a seed-source bank for natural regeneration along with structural features (standing deadwood, old growth trees) considered of significant importance for biodiversity.

Table 1. *Overview of the 18 sites used during this experiment showing; site location, ownership, former land use, and percentage share of Quercus in the*

	Site	County	Ownership Status	Former land use	Oak in overstory (%)	Major tree species[a]
	Sweden					
1.	**Aplared**	*Västra Götaland*	*Municipality*	*Wooded pasture, meadow*	32	*Quercus , Corylus avellana, Fagus sylvatica*
2.	**Aspanäs**	*Östergötland*	*Private*	*Wooded pasture*	9	*Sorbus aucuparia, Picea abies, Corylus avellana*
3.	**Bosnäs**	*Västra Götaland*	*Municipality*	*Pasture, meadow*	51	*Quercus, Betula pendula, Populus tremula*
4.	**Hovetorp**	*Östergötland*	*Private*	*Pasture, meadow*	15	*Corylus avellana, Acer platanoides, Quercus*
5.	**Klockaretorpet**	*Östergötland*	*Municipality*	*Field, pasture, meadow*	30	*Corylus avellana, Quercus, Populus tremula*
6.	**Kvarntorp**	*Östergötland*	*Private*	*Pasture, meadow*	7	*Corylus avellana, Populus tremula, Quercus*
7.	**Motala**[b]	*Östergötland*	*Municipality*	*Pasture, meadow*		-
8.	**Remmene**	*Västra Götaland*	*State*	*Pasture*	49	*Quercus, Picea abies, Betula pendula*
9.	**Slaka**	*Östergötland*	*Municipality*	*Pasture, meadow*	18	*Betula pendula, Populus tremula, Quercus*
10.	**Stöpen**	*Västra Götaland*	*Municipality*	*Pasture, meadow*	7	*Corylus avellana, Picea abies, Fraxinus excelsior*
11.	**Tullgarn**	*Stockholm*	*State*	*Wooded pasture, meadow*	29	*Quercus, Picea Abies, Betula pendula*
12.	**Tvärsjönäs**	*Västra Götaland*	*Private*	*Pasture*	17	*Corylus avellana, Picea abies, Quercus*
	Norway					
13.	**Berg**	*Vestfold*	*State*	*Wooded pasture*	6	*Fraxinus excelsior, Alnus glutinosa, Picea abies*
14.	**Håkås**	*Østfold*	*Private*	*Pasture*	1	*Picea abies, Fraxinus excelsior, Ulmus glabra*
15.	**Karljohans-vern**	*Vestfold*	*State*	*Military training ground*	3	*Corylus avellana, Acer platanoides, Fraxinus excelsior*
16.	**Kåpe**	*Vestfold*	*Private*	*Pasture*	23	*Corylus avellana, Quercus, Picea abies*
17.	**Sand**	*Vestfold*	*Private*	*Field, pasture, meadow*	11	*Corylus avellana, Alnus glutinosa, Fraxinus excelsior*
18.	**Svartskog**	*Akershus*	*Private*	*Field, pasture, meadow*	2	*Betula pendula, Picea abies, Salix caprea*

[a] *Based upon basal area share*

[b] *No inventory for Motala in 2016*

Oak seedling inventory

Within each plot an oak seedling inventory was conducted at the start of the experiment in 2016 and at the end in 2019.

The site layout was as shown in figure. 4, with two parallel transects (T1, T2) that ran the full length of each plot (100 m) and were separated by approximately 50 m. Both transects were divided along their length into four equal sections each of which are 25 meters (Section 1 is from 0-25 m and so on). In the first and the third section along each transect in all plots, the height of all oak seedlings within two meters of the transect on each side was measured in centimetres. Oak stems have been categorised into three classes in accordance with a previous study by Götmark et al. (2005). Stems between 0 and 20 cm are regarded as seedlings (*Class 1*), stems between 20-130 cm are short saplings (*Class 2*) and those stems longer than 130 cm are tall saplings (*Class 3*).

Figure 4. *Typical site layout. The site shown is Kvarntorp, showing both plots; control and treatment as well as an example of how the transects are laid out (T1, T2).*

Source:Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

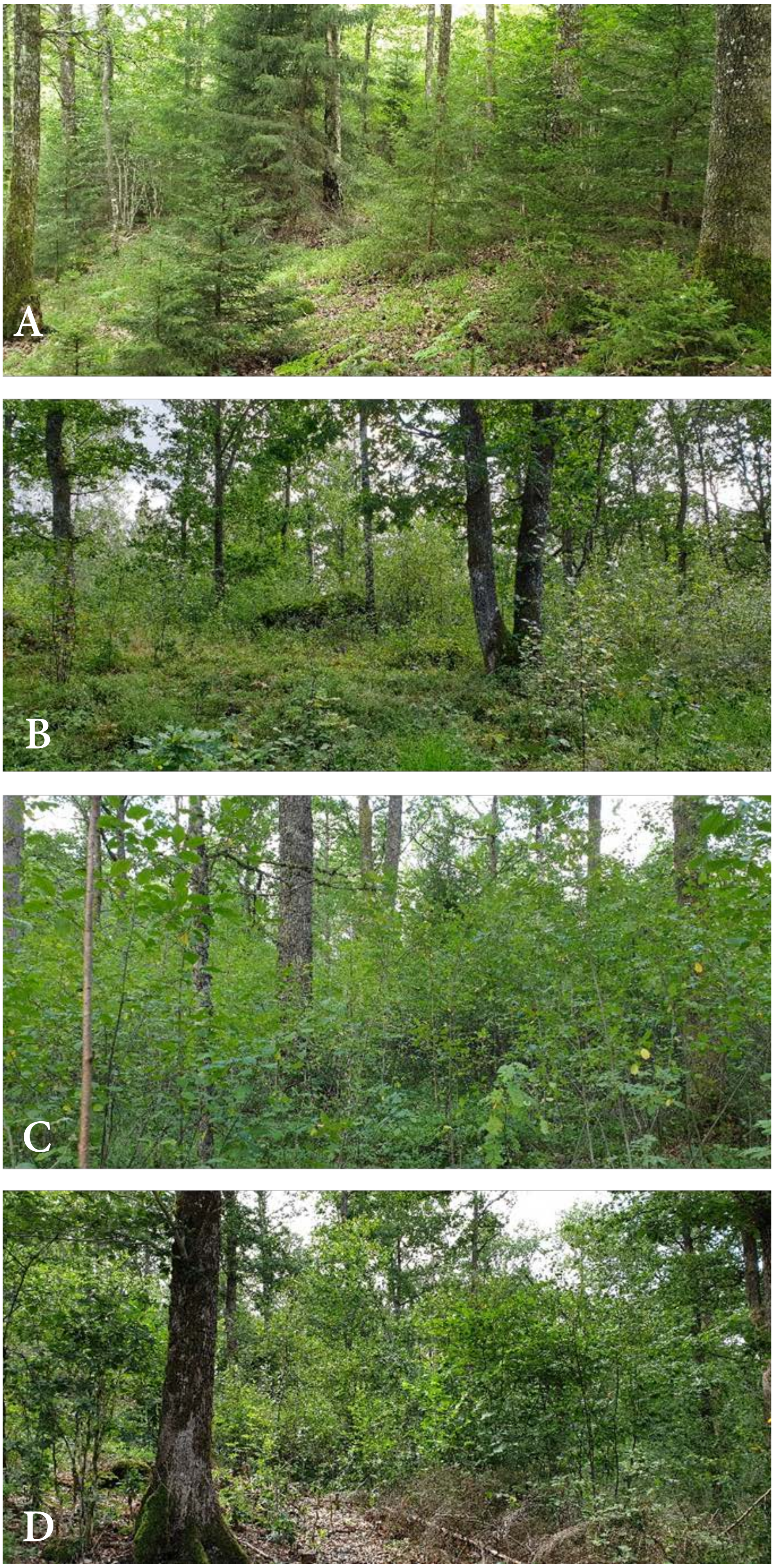

Figure 5*. A photo series depicting Control and Treatment plots in 2019. (A) Tvärsjönäs Control (B) Tvärsjönäs Treatment. (C) Bosnäs Control (D) Bosnäs Treatment.*

Photo: Samuel Keith

Light transmittance and basal area measurements

In order to evaluate the relationship between light availability, seedling growth and density, a series of hemispherical photographs were taken at each plot (for an example image see Figure 6) at pre-determined points along both transects. This type of photography is a favoured optical technique in the study of canopy structure and understory light transmission, especially useful in the study of seedling development and mortality (Frazer et al. 1999). The procedure was similar to that described in Löf et al. (2007). Conducted in early August whilst the trees were still in leaf, four skyward orientated photographs were captured during the early hours on relatively overcast conditions to avoid direct sun-flare on the camera lens. The camera (Nikon Coolpix 8800 VR) and fisheye lens (LC-ER2) was mounted on a tripod at a height of 160 cm held perpendicular to the forest floor together with spirit level. The magnetic north was indicated in each photo to allow for correct orientation of the images during later analysis. The uncompressed original photographs were then processed using Gap Light Analyser (Frazer et al. 2000) thresholding the images in the blue plane to give the clearest contrast between tree canopy and open sky (Frazer et al. 2001). The program computes canopy openness as well as the amount of total (direct and diffuse) below canopy solar incident radiation. Hemispherical photography has a number of advantages over alternative methods such as fixed/handheld light sensors, and plant canopy analysers. These may include, ease of processing (digital imagery allows for an immediate review of the image) and once set up the equipment is relatively easy to operate and good estimation of growing season light transmittance (Comeau et al. 1998). In 2019 an estimation of the basal area was made using a relascope counting only whole values (stems that filled the relascope meter) at the same points as light transmittance measurements were taken giving a total of 72 measurements. In contrast to the 2016 inventory the basal area count was not species specific and has the intention to give a simple description of the relation between basal area and light transmittance at a specific point.

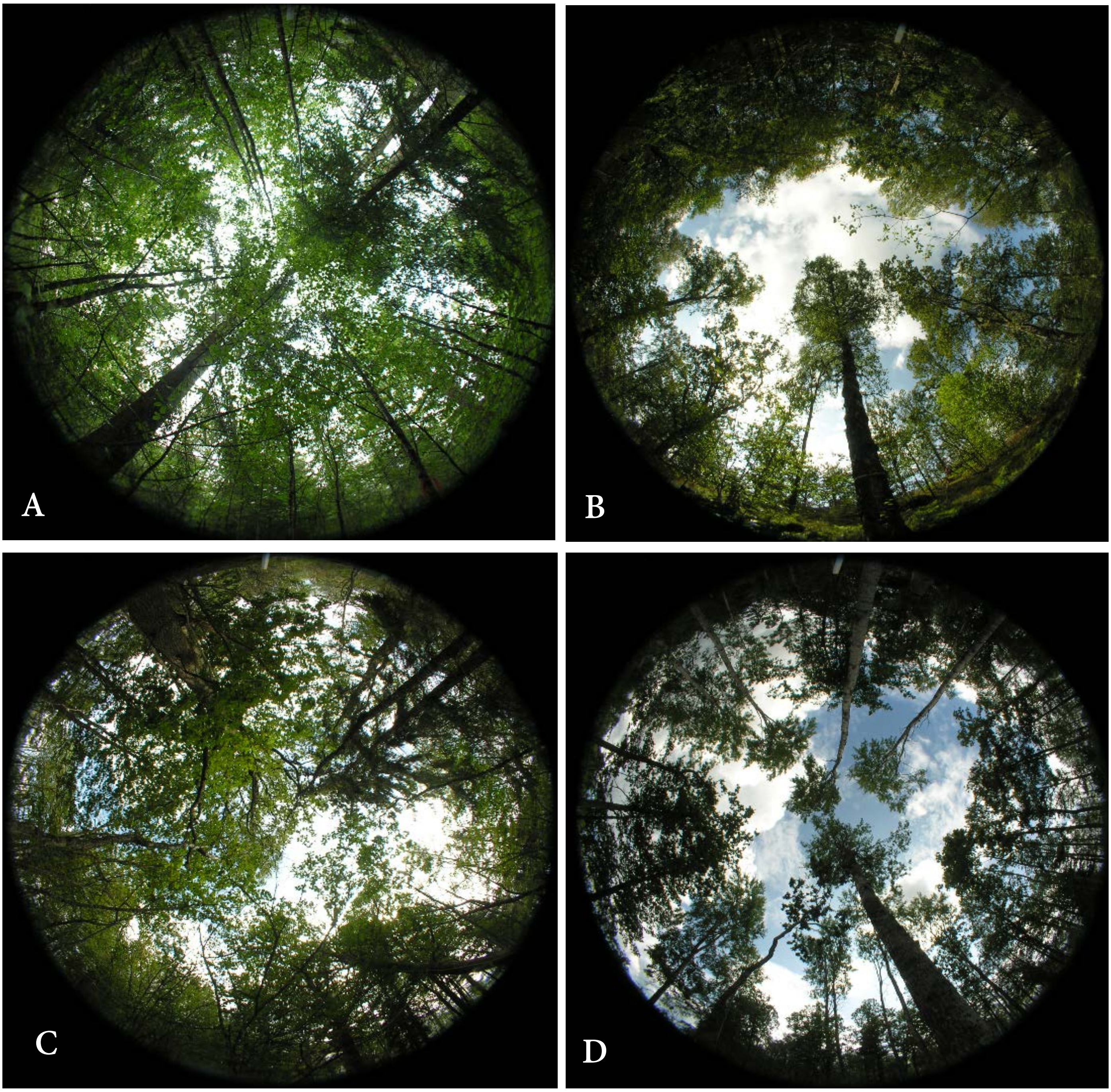

Figure 6. *A Series of typical hemispherical photographs prior to processing.*

Site: Remmene; Control (A) , Treatment (B)

Hovetorp; Control (C) , Treatment (D)

Photo: Samuel Ketih

Data analysis

Total seedling density is based upon an extrapolation of the stem inventory data which provided the number of stems for four individual sub-plots per site (each 100 m^2 in size). The density per hectare is therefore an average value per site and per year which has also been categorised by height class as described above. Seedling recruitment is considered as the number of new individuals that have entered the population (Ribbens et al. 1994) under a given time frame. In this study, the number of recruited seedlings is estimated by subtracting the number of stems in *Class 1* in 2016 from the number of *Class 1* stems in 2019. Thereafter changes in stem density amongst height classes and light transmittance have been analysed using paired t-tests in Microsoft Excel to evaluate if changes in between years and treatment types can be considered statistically significant. A basic regression analysis has been used to review the strength of the relationship between changes in light transmittance and seedling density, as well as basal area using the ANOVA function in R studio. Due to inconsistencies in the dataset, calculations for stem density analysis are based on eleven of the twelve Swedish sites (oak inventory data for Kvarntorp in 2016 is not available) and the calculations regarding basal area are from all eighteen sites in total.

As a further effort to analyse the effect selective cuttings have had upon the oak regeneration, the change in average height has been calculated for stems in *Class 2* and *Class 3*. All stems in *Class 1* have been excluded from this calculation in order to reduce the recruitment effect, i.e. height growth is intended to be based upon those stems that existed before the treatment. The decision to exclude *Class 1* stems was made to keep continuity with the experiment in the absence of data regarding individual stem development, as seedlings under 20 cm are viewed as new individuals. Therefore, change in average height was expected to represent seedlings present prior to intervention.

3. Results

Seedling density and recruitment

The average change in total stem density per height class between 2016 and 2019 is shown in Table 2 summarised by a paired t-test. It was deduced that the difference in stem density between control and treatment plots throughout all height classes was statistically insignificant (p >0.05). This is considered as an important factor to note in the premise of a before-and-after comparison, giving both treatment and non-treatment plots an even starting point.

Stem density change between years is considered non-significant when grouping all height classes together. However, should each height class be considered as an individual population then treatment plots show a significant increase in the recruitment of *Class 1* seedlings (p 0.04) under the duration of the experiment. Control plots have on average also gained a great number of seedlings in *Class 1* which is also regarded as a significant change compare to the density in 2016 (p 0.05). Having gained almost as many seedlings in control as in treatment plots within *Class 1* has weakened the clarity of a treatment effect (p >0.1).

On the whole, treatment plots gained ~460 more seedlings/ha (*Class 1*) than in control plots, 330 more short saplings (*Class 2*) (p 0.06), and 2 fewer tall saplings (*Class 3*). The large gain in *Class 1* was most evident in treatment plots with 3 sites; Tvärsjönäs. Bosnäs and Klockaretorpet which all gained over >5000 new stems/ha. Only one treatment plot (Hovetorp) had fewer *Class 1* stems in 2019 than in 2016 compared to four control plots. The sites with the largest number of seedlings had also the highest density of short saplings.

Table 2. *Average stem density for control (C) and treatment (T) plots. Class 1 (0 – 20 cm) Class 2 (20 – 130 cm) Class 3 (>130 cm),* n*=11*

	Class 1			Class 2			Class 3		
	C	T	*p - value*	C	T	*p - value*	C	T	*p - value*
2016	291	268	*0.85*	268	184	*0.37*	5	5	*1*
2019	1930	2371	*0.32*	620	873	*0.06*	18	16	*0.86*
p-value	*0.05*	*0.04*		*0.24*	*0.13*		*0.26*	*0.51*	

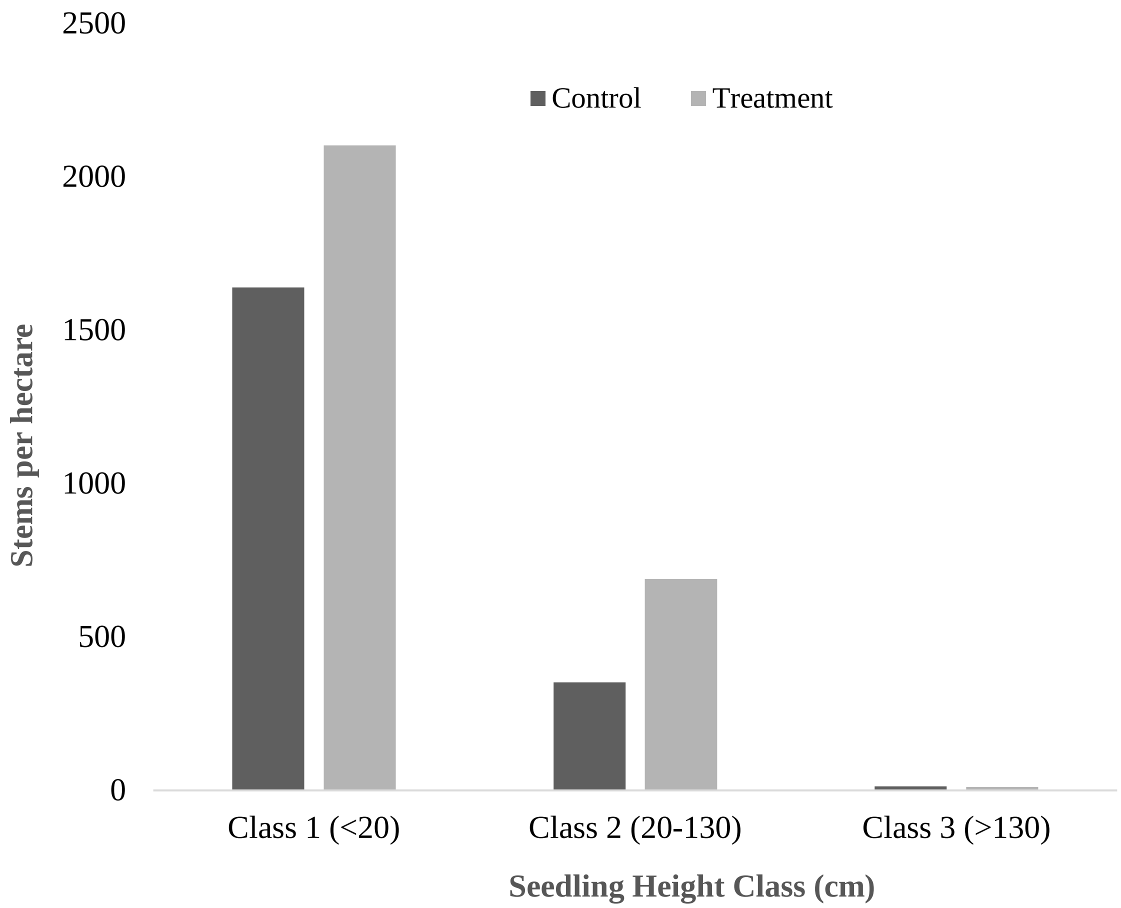

Figure 7. *Shows the average change in the number of stems per height class between 2016 and 2019 for control and treatment plots (n = 11). Both control and treatment plots show a significant gain in seedlings <20cm.*

Light transmittance

Selective cuttings have successfully lowered basal area and raised the average avilable light level in the understory. The increase in light Transmittance (Figure 8) is on average 5% higher in treatment plots (30% of and open canopy) than in the control plots (25%) and is regarded as a statistically significant ($p < 0.001$) difference between treatments. As with the oak seedling inventory data, there is large variance within the light measurments, with both the highest (Tullgarn – 39%) and lowest (Kvarntorp – 18%) found in treatment plots. The basal area measurements display a similar trend, although the treatment effect is somewhat greater, the data is affected by large fluctuations between the same treatment types at different locations. Analysis of the interaction between basal area and light transmittance displays the expected result that the heighest light transmittance is achived at lower basal area ($p<0.05$).

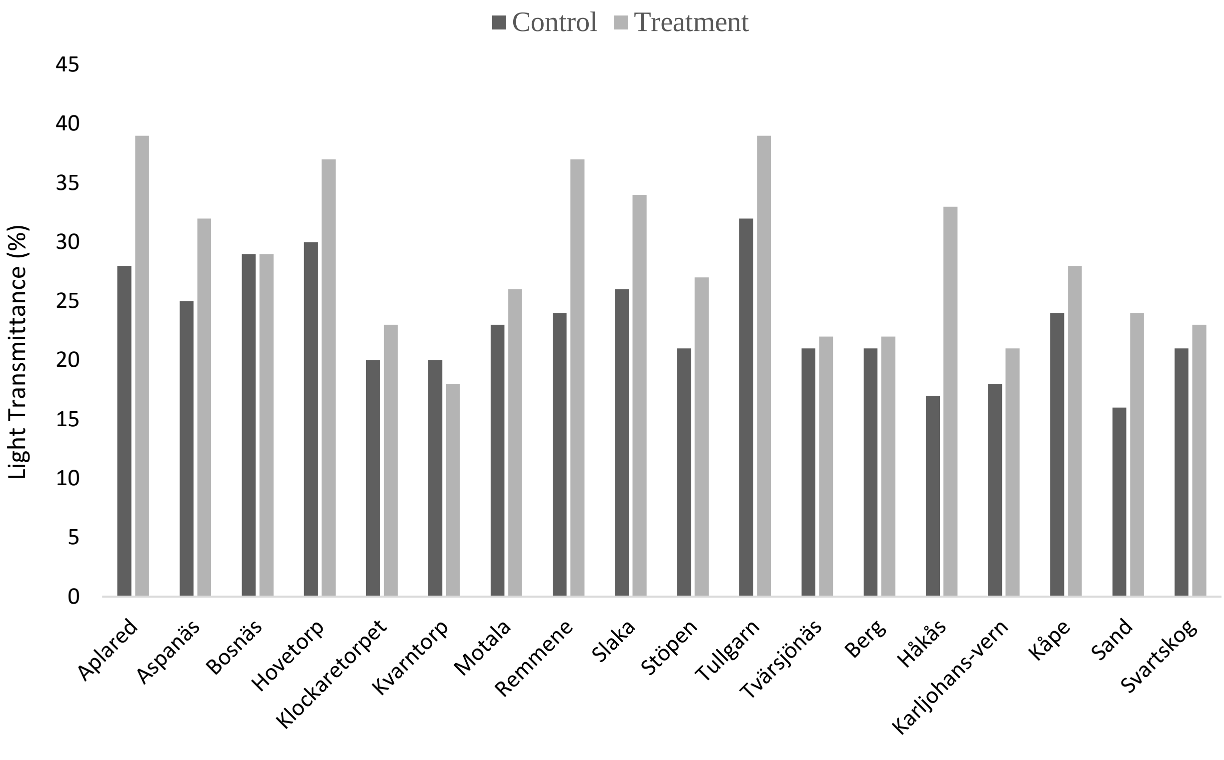

Figure 8. Average light transmittance per site for all 18 locations in both control and

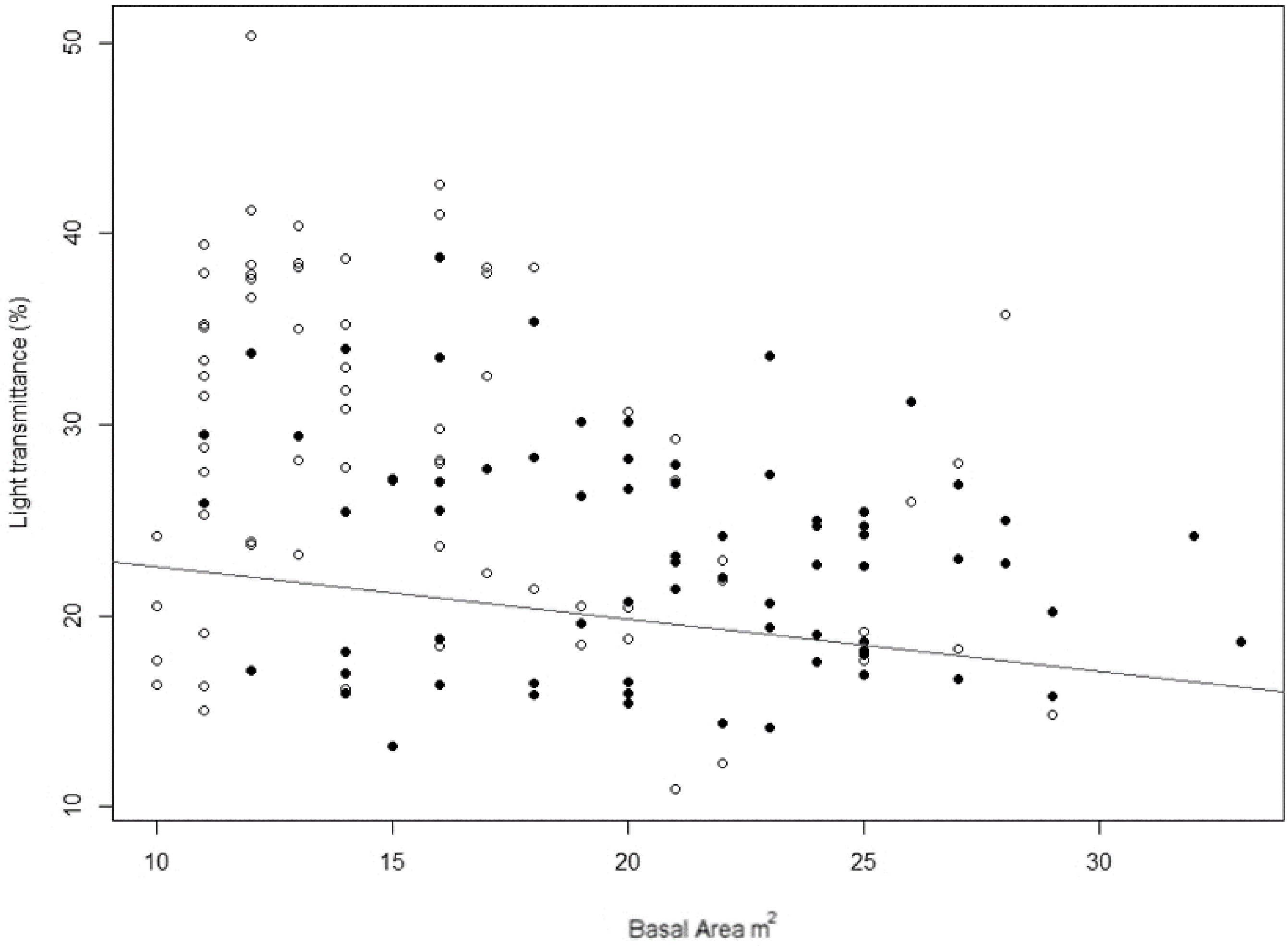

Figure 9. *Basal area in relation to light transmittance based on measurements from four points at all 18 locations*

Seedling density in relation to light transmittance

It proved challenging to identify a solid relationship between stem density and light transmittance. More evident in figure 10, is that the plots with the greatest percentage of light transmittance are not those plots with the highest number of seedlings. A weak negative correlation was found within *Class 1* seedlings (p 0.05, R^2 0.18) and even one of the sites with highest light transmittance (Hovetorp) showed a decrease in number of seedlings < 20 cm between 2016 and 2019. The relationship between light and seedling density proved weaker in both Class 2 and Class 3 ($p > 0.1$) despite a higher light transmittance in treatment plots, which was anticipated to benefit sapling density.

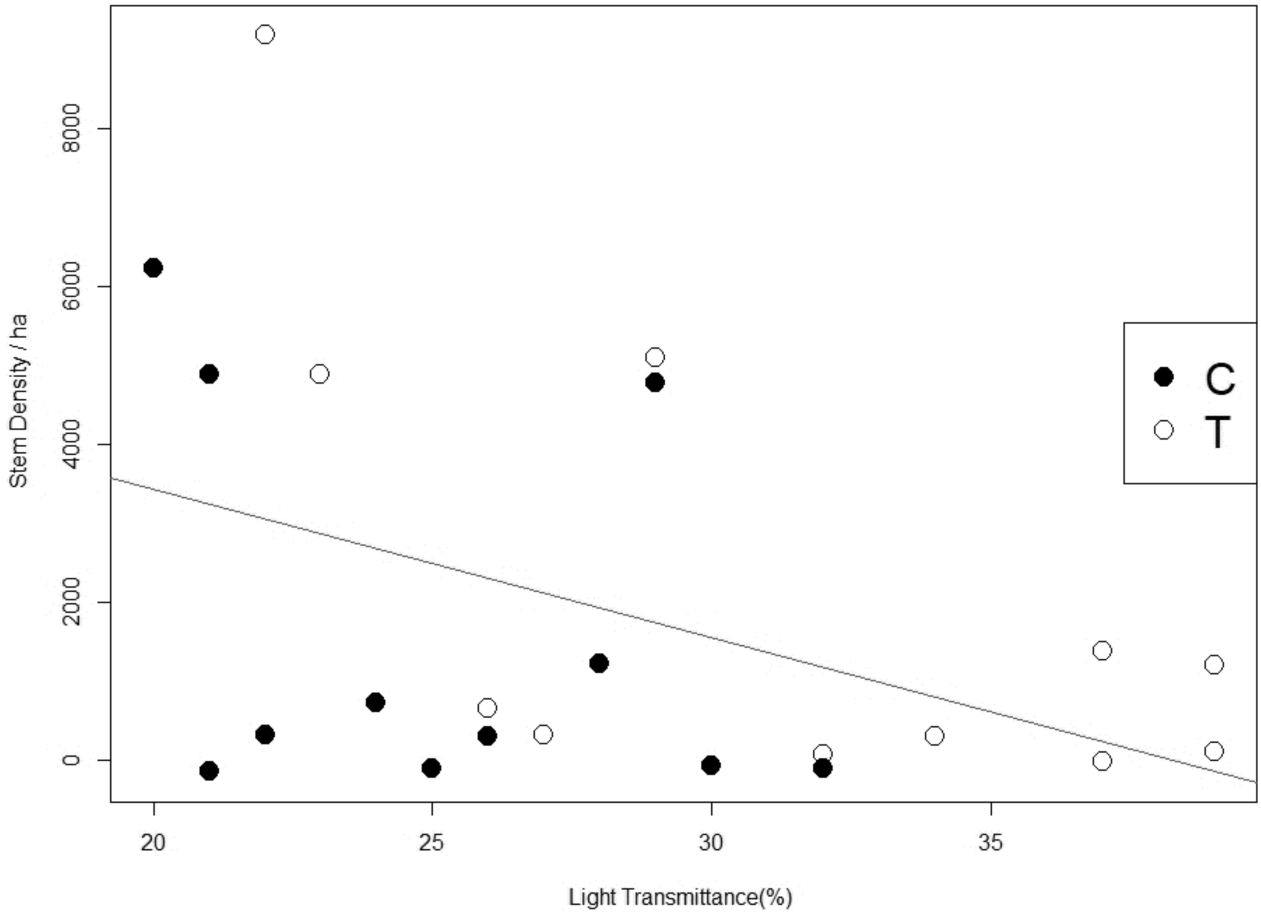

Figure 10. *Stem density of Class 1 seedlings in relation to light transmittance in 2019*

Growth in stem height

An estimation of growth in stem height has been made to further evaluate the potential effects of selective cuttings. The change in the average stem height for *Class 2* and *Class 3* stems (grouped) shows a varied response following intervention in 2016. Overall, average stem height has decreased by 8 cm in control plots and 4.5 cm in treatment plots. Of course, stem height in this regard is directly related to the change in stem density. Tvärsjönäs indicates the greatest increase in average stem height over 20 cm and is also one of the sites that had the greatest increase in overall stem density, however a lower than average available light in both control and treatment plots. Several of the sites display a negative change in stem growth in Class 2 and Class 3 and this is associated to a decrease in the number of stems found in those height categories. Slaka in Östergötland is a prime example which had 225 seedlings >20 cm in treatment plots in 2016 and only 25 seedlings >20 cm in 2019.

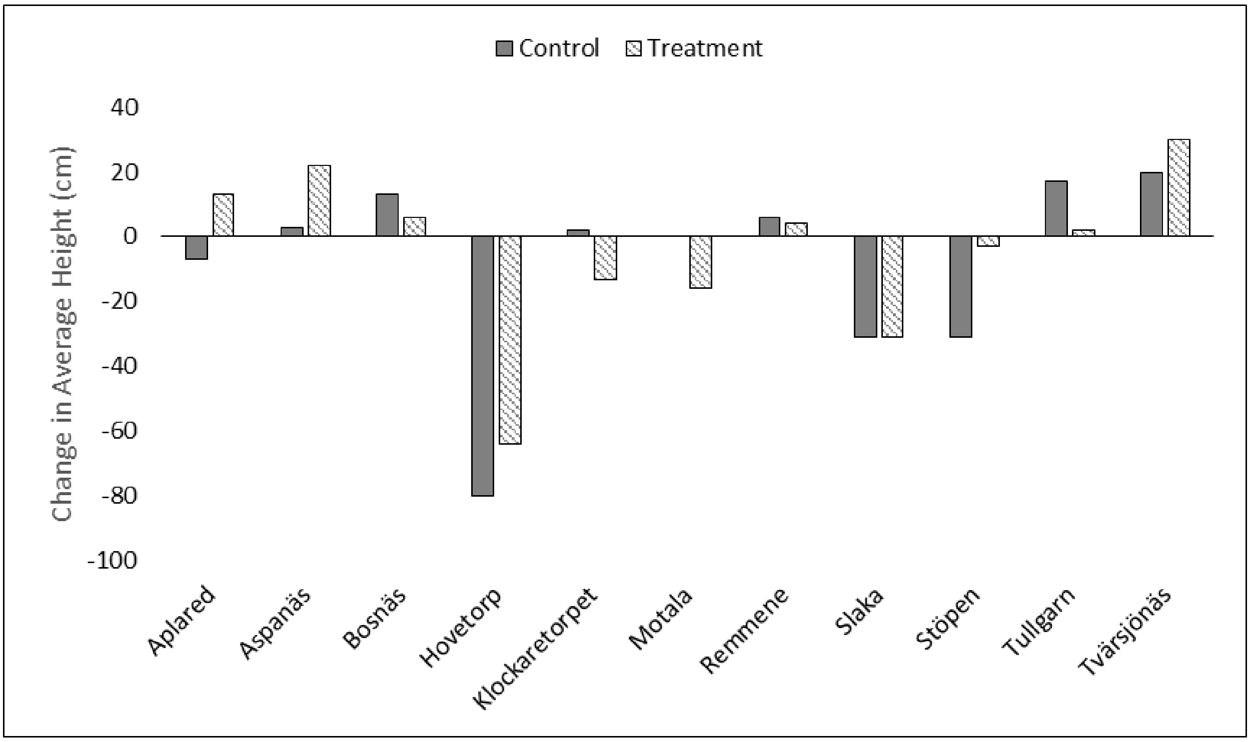

Figure 11. *Change in average stem height between 2016 and 2019. All stems >20cm (i.e. Class 2 and Class 3) are accounted for, stems in Class 1 have been excluded from the calculation in an attempt to remove a recruitment effect.*

4. Discussion and Conclusions

General discussion

This study set out with the intention to investigate if selective cuttings alone have significantly increased natural oak regeneration and whether increased stem density can be attributed to an increase in light availability.

Overall, one can make quite different assumptions depending upon which part of the dataset is considered. The total stem density i.e. all height classes compiled together, did not increase in response to an increase in light availability. That said, the response of stems in *Class 1* and *Class 2* is most significant in treatment plots, where light transmittance is generally higher. It is assumed that selective cuttings have had a positive effect upon recruitment and development of seedlings up to 130 cm, although the treatment effect itself is not proved to be exclusively associated with increase in light availability.

To assume that a manipulation of the understory light availability would result in a large improvement of the natural regeneration would be to assume that light is the only deciding driving force at play. Of course, there are other factors to consider, one of which is the capacity of seedling to respond to a change in their surroundings. Oak seedlings have been descried as displaying good plasticity in how they respond to changes in light availability, but it is not necessarily an increase in height growth that occurs first. Saplings can also opt to set more buds and increase leaf area in an effort to capitalise on more light or hedge their bets by using extra light to refill root-energy stores. It is therefore understandable to expect a time lag effect before an increase in stem densities throughout *Class 2* and *Class 3* height groups occurs and may only be realised once the recruited stems in *Class 1* progress. Alternatively, it could be speculated that the large gain in seedlings that occurred in both control and treatment plots was resultant of a large influx of acorns following a mast year that occurred under the duration of the experiment. The successful establishment of oak seedlings following a mast year has been previously been described as enhanced by forest disturbances (Abrams & Johnson. 2013).

Timing of the selective cuttings may have been out of sync with the oak mast year. Selective cuttings that take place in the years following a mast year may be too little too late, oak seedlings can be less responsive to changes in their surroundings with age and can have a difficult time recovering if released from shaded environments (Schütz et al. 2016). So perhaps cuttings should be made in the same year as a mast year is expected. With that in mind, if 2019 was a mast year then there is potentially a time lag and the seedlings would not have shown themselves until the following year and have been obscured by the experiment.

In earlier studies, the progression of plants through various demographic stages is described as under the control of both plant consumers; fire and herbivores, and plant resource availability; light, water, and nutrients (Churski et al. 2017). High resource environments (i.e. high proportion of incoming solar radiation reaching the understory), such as in selectively cut plots, are suggested to alleviate stress and allow plant communities to overcome the pressure imposed by consumers (Bond 2005). As oaks are amongst the most palatable of tree species for wild ungulates, high resource environments have the potential to offer a way out of the what otherwise keeps them within a *'browsing trap'* (Staver & Bond 2014). However, there is strong evidence that browsers can also respond to an increase in resource availability in a similar manner that plants do, and any improved seedling growth is therefore subdued by an increased browsing intensity, hence maintaining the browsing trap (Churski et al. 2017). Ungulate populations are high in Scandinavia, especially in southern Sweden (Peterson et al. 2019b) which can be considered as a considerable browsing potential. In temperate forest ecosystems, ungulates favour browsing in gaps (Kuijper et al. 2009) which brings them into direct conflict with oak seedlings that have established in openings following selective cutting. Although no browsing data is available for this particular study, earlier research points out that increased browsing pressure is detrimental to oak regeneration, Churski et al. (2017) simulated a 40 year experiment in which even the fastest growing oak seedlings in high light environments were unsuccessful in escaping the browsing trap of a height over 200 cm. Seedlings under 20 cm are largely unaffected by ungulate browsing (Götmark et al. 2005) which could explain why the results showed a significant gain within Class 1 stems and may offer some explanation into why the number of seedlings progressively decreases from *Class 1* to *Class 3* and suggests that any treatment effect may be muted by an overpowering browsing trap. The understory available light is on average 5% higher in treatment plots with a mean light transmittance of 30% of that of an open canopy. Basal area is often used in estimating light transmittance and is popular mainly due to its simplicity to measure. The results shown here highlight an underlying relationship between basal area and light transmittance but however confirm that practicality is potentially outweighed by accuracy whereby two stands of similar basal area can have totally different light levels. Unsurprisingly, this is exasperated in mixed stands in which crown structure and stem arrangement is less uniform to that of a planted forest. Oak seedlings are capable of surviving in shaded environments at early ages even after the carbohydrate storage in the acorn begins to run out (Löf et al. 2019) but require a minimum of 15-20% light availability to be able to sustain growth (Ligot et al. 2013; Löf 2007). Although the average light availability in both control and treatment plots is higher than the perceived minimum required, it may not be enough for oak to dominate in the understory and therefore partly explain why oak is not the dominating species amongst short and tall saplings.

In an effort to explain why the relationship between light and seedling density has perhaps been as strong as expected. I speculate that in the absence of protection against browsing, the average light transmittance following selective cutting could be too low to allow significant oak regeneration, since most other studies tend to separate browsing and light availability as separate variables. According to Modrow et al. (2020), significant height growth of sessile oak seedlings and survival over competing vegetation was only realised in situations when light availability was greater than 50% of an open canopy. The TransForest experiment has implemented an approach of small-scale selective cutting which focused on reducing basal area whilst maintaining a large proportion of adult oak stems in the canopy. It could be that the disturbance effect that this type of intervention has had is too weak to favour oak regeneration and a more radical approach is needed i.e.

creation of larger gaps. This is supported by other research which points out that oak displays continual successful regeneration following stand replacing disturbances (Petritan et al. 2017) and that this is only replicated in interventions that create gaps in the order of 0.2 ha (Von Lüpke 1998). In management regimes that open the canopy to a smaller degree, gaps are at risk of being filled by faster growing species such as birch, ash and maple (Jaloviar et al. 2020). Overtopping of oak seedlings by these faster growing species is detrimental to the progression of oak through the understory. In my study, although there is no inventory of what other species exist in the regeneration, from personal field observations both birch and ash have been profuse in the regeneration throughout the sites and may have outcompeted any oak seedlings. The TranForest removed on average one fourth of the basal area in 2016, which could have been too little to favour oak regeneration. Reasons for this have been discussed in relation to the practicality of removing a larger basal area would have resulted in the extraction of oak stems to for fill the quota at those sites that have had the largest share of oak prior to cutting as well as the risk of increasing damage due to windthrow with larger removals (personal contact, TransForest[1]).

Potential shortcomings lie within the process of selective cutting itself, with most of the sites making use of a forwarder to remove felled trees, there is a risk that despite best endeavours, that oak saplings have been damaged in the harvesting process. This may offer some explanation as to why a few treatment plots had seedlings >20 cm in 2016 but which had disappeared from the inventory in 2019. The height growth calculations pose also a number of short comings. Most importantly, the average change in stem height doesn’t not adequately represent the ‘response’ of stems to changes in light availability. A more suitable method could have been to track individual stems marked under the course of the experiment and use the relative growth rate in height (Petersson et al. 2020). In this way a more accurate picture could be established over how stems reacted in light rich or light poor environments as well as accounting for unknown stems that have vanished from the inventory. Measuring changes in height growth may be a more suitable analysis for taller stems, whereas measuring seedling density is appropriate for

[1] M. Löf, Professor, SLU, e-mail 02-06-2020

recruitment of new individuals in which height growth more a function of carbohydrate resources in the seed prior to germination.

Consideration of the importance of oak rich environments

Oak is part of the long-term ecological record in southern Scandinavia and central Europe (Foster & Lindbladh 2010). The long-lived nature of oak trees and its persistent nature as a deadwood substrate has made it a feature in many forests. The current difficulties associated with its regeneration pose a threat to oak rich habitats. Having a substantial influence upon its immediate surroundings, oak is considered a foundation species (Ellison et al. 2005; Jensen & Hansen 2008), regarded as being fundamentally important in driving and sustaining a range of ecological processes. It is widely described (Ranius & Jansson 2000; Ranius et al. 2005; Mestre et al. 2018; Koch Widerberg et al. 2018) that oak trees provide a diverse range of habitats which are crucial for the survival of a vast number of invertebrates, lichen, mammalian, and fungi species alike. In some cases, species are directly dependent upon specific substrates found within the cambium as a source of food or nesting material e.g. *Osmoderma eremita* (Ranius et al. 2005) and in other cases species are inherently related to morphological/ecological traits of oak that cannot be provided by other species (Ranius et al. 2005). In the case of the white backed woodpecker (*Dendrocopos leucotos*), a red-listed species, not found in forest plantations, is strongly dependent upon structural characteristics found only in freely developed broadleaf-dominated forests (Gerdzhikov et al. 2018). Similarly, a large variety of saproxylic beetles Sweden are closely tied to the presence of large old oaks (Ranius & Jansson 2000; Koch Widerberg et al. 2018). Specialist species are adapted to specific habitat characteristics that develop gradually over a long time period and a sudden land use change from an open oak landscape to a production conifer plantation can cause a breakage in the ecological continuity of species-specific habitats (Mölder et al. 2019 and references therein). The security of species rich habitats associated with oak is tightly bound to how future resource management and climate mitigation policies unfold. Striking a balance between production goals and biodiversity is not a new concept, but certainly one that will continue to dominate forest and climate research discussions. Acknowledgement of the potential for habitat preservation and restoration that is found in small clusters of broadleaf rich forest within an agricultural landscape is an important steppingstone in the conservation of biodiversity (Brunet et al. 2019). Further research into the habitat qualities found at such sites could contribute to securing these areas under Key habitat schemes and reduce the need to find an economically valid excuse to manage for biodiversity. Project such as the TransForest project should be used as an example for how management strategies should strive to be both economically and ecologically flexible in their goal setting.

Conclusions

The results from this study are characterised by small and slight glimpses of hope for oak regeneration, most of which is confined to the recruitment of seedlings <20 cm. The most important achievement of this experiment has been in securing a recruitment of the smallest stems which is just the first step in establishing ecological continuity. The findings from larger well-established studies (e.g. Götmark 2007; Leonardsson et al. 2015) make quite clear linkage between light availability, selective cuttings and improved oak regeneration. The absence of fencing in my study is partly due to fulfil cost-effectiveness during restoration. Fencing is deemed too expensive to be used on a large scale in most cases (Löf & Birkedal 2009) and is worth considering depending on the management goals. For forest restoration projects, this poses a conflict between the economic opportunity cost and the ecological, and for that reason the long-term goals need to be clearly specified and weighed into account. If securing a successful oak regeneration is the main and most valued objective then small-scale fencing around gaps may be 'worth the cost', especially considering the potential to use dead-wood material as a source of fencing material (Bradfer-Lawrence & Rao 2012) On the other hand, a minimal gain of oak in the understory could be deemed an acceptable by-product of gap creation related to other biodiversity objectives. Currently in Sweden, forest owners can apply for financial aid to establish fencing of up to 80 SEK/m from the Forest Agency (Skogstyrelsen 2020). The subsidies are specifically directed to support the management or establishment of temperate broadleaved forests, primarily the grant is approved for sites that are already considered broadleaf dominated, but consideration is also paid to restoration sites such as those used in the experiment.

Selective cuttings have created a light richer environment through the targeted removal of individual stems, which has been widely distributed across the plot (personal observation in field) and as discussed above this arrangement of gap opening may not be optimal for oak regeneration. Gap creation requires accurate timing to take advantage of mast years and reoccurring intervention. Not all species-specific requirements can be met by a single selective cutting. As oak is both suppressed by browsing and outcompeted in light right environments, it may be necessary not only to remove shade tolerant species like Norway spruce but also other fast-growing broadleaves from the overstory to reduce their seed banks. Follow up interventions could in this scenario be beneficial to dampen the natural regeneration of fast-growing species and reduce resource competition. In many cases, forest that have formed on abandoned agricultural land area under private ownership and communication with land owners could provide either incentive for them to partake in the practical management (clearance, fence maintenance etc.) or to come to agreement over how adaptive management could benefit the flexibility of their forest an contribute both to gains in biodiversity and economic viability in the long run.

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