Changes in the oak (*Quercus robur*) population in Dalby Söderskog national park 2011–2020

– stem size distribution, spatial distributions, vitality and mortality

Förändringar i Dalby Söderskogs ekbestånd 2011–2020 – fördelning av stamstorlekar, rumslig fördelning samt vitalitet och mortalitet

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Master's thesis in Biology • 30 hp
Swedish University of Agricultural Sciences, SLU
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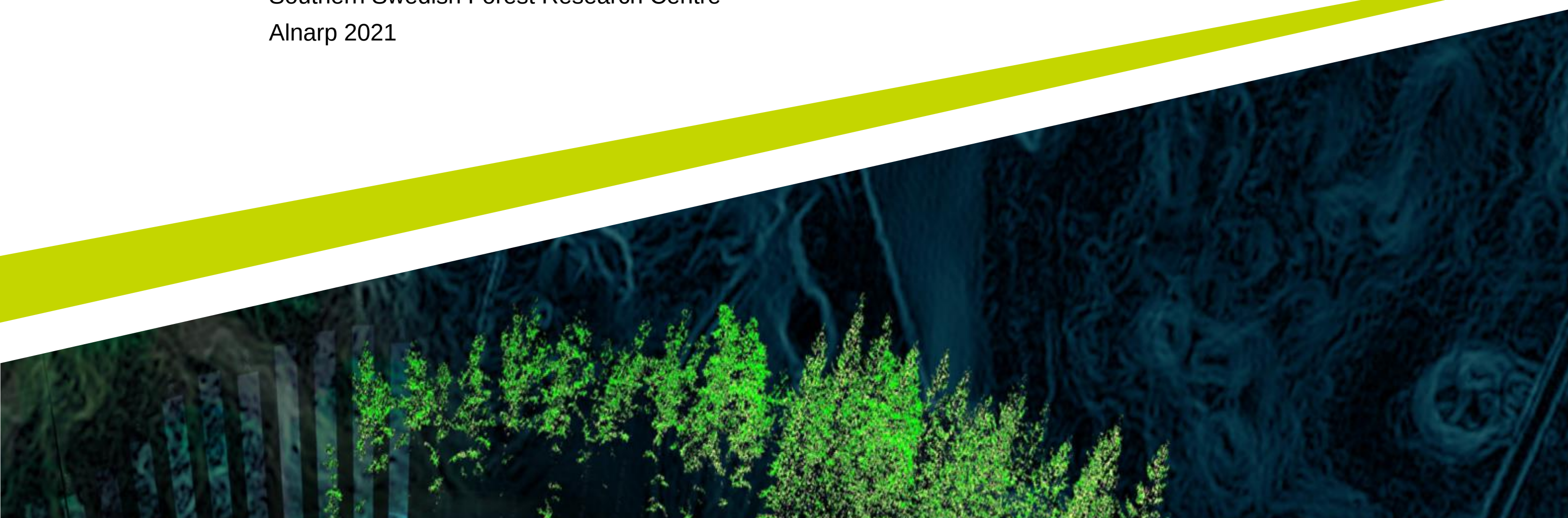

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Abstract

A recent oak (*Quercus robur*) decline has been noticed and studied in Europe during the last few decades. This decline in combination with failure in natural regeneration could threaten not only oak populations, but also oak-associated species. In Dalby Söderskog national park in southern Sweden, the last survey on oak was carried out in 2011 and showed that the number of living oaks had declined since 1935. Although only nine years have passed since the latest survey, a new inventory has become ecologically relevant due to rapid disease-related changes in the ash and elm populations which, in turn, may affect both the vitality of old oaks and the conditions for oak to regenerate. In the inventory for this thesis, living and dead oaks above 10 cm in stem diameter (dbh) were surveyed. The data collected for each tree was: dbh, coordinates and vitality.

Results show that the mortality rate in the oak population of Dalby Söderskog is still unchanged, although the first substantial regeneration of oak can be seen in the forest for the first time since 1935. In the thesis, changes in the tree community of the forest and possible future approaches from a nature conservation perspective are discussed.

Keywords: forest reserve, national park, long-term study, oak, oak regeneration, Quercus robur

Sammanfattning

En så kallad ekdöd som drabbar ek (*Quercus robur*) har uppmärksammats och studerats i Europa under de senaste decennierna. Denna nedgång i kombination med misslyckad naturlig föryngring kan hota inte bara ekpopulationer, utan även ek-associerade arter. Den senaste undersökningen av ekpopulationen i Dalby Söderskog gjordes 2011 och visade att antalet levande ekar har minskat stadigt sedan 1935. Trots att endast nio år har passerat sedan den senaste inventeringen är en ny inventering ekologiskt relevant på grund av snabba sjukdomsrelaterade förändringar i ask- och almpopulationerna. Dessa förändringar som i sin tur kan påverka både vitaliteten bland gamla ekar och förutsättningarna för ekföryngring. I inventeringen för denna uppsats undersöktes levande och döda ekar över 10 cm i stamdiameter (dbh). Data som samlades in var dbh, koordinater och vitalitet.

Resultaten visar att mortaliteten bland Dalby Söderskogs ekar fortsätter oförändrat, men även att en ny föryngring av ek pågår i skogen – den första föryngringen av betydelse sedan 1935. Förändringarna i trädskikten diskuteras i uppsatsen även utifrån ett naturvårdsperspektiv med förslag på eventuella framtida insatser.

Nyckelord: naturreservat, nationalpark, långtidsstudie, ek, ekföryngring, Quercus robur

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Abbreviations

BA	Basal area – the cross-sectional area of a tree stem at breast height (130 cm above ground). BA is often reported as the sum of BA's in an area – usually *basal area per hectare* (BA/ha).
DBH	(Stem-)diameter at breast height – measured on the stem at 130 cm above ground.
DED	Dutch elm disease
GIS	Geographical Information Systems
PPM	Pathogen powdery mildew
SLU	Swedish University of Agricultural Sciences

1. Introduction

1.1. Background

Mixed deciduous forests used to cover much of northern Europe, but due to human interventions, such as deforestation in favour for agriculture, this vegetation type has decreased gradually (Vera 2000). For pedunculate oak (*Quercus robur*), the most important canopy species in such forests, pollen analysis indicates that it has kept decreasing in southern Scandinavia during the last 4000 years (Lindbladh & Foster 2010). In Sweden, 43% of all species – more than 2000 species – on the national 2020 Red List of Swedish Species (based on international IUCN criteria) have forests as their main habitat (Artdatabanken 2020). Pedunculate oak and sessile oak (*Q. petraea*) are known to be able to provide habitat for more than thousand other species – of which many are obligate associates – and are therefore considered important keystone species in Europe (Mitchell *et al.* 2019).

Old tree structures such as coarse bark and hollows makes an important habitat for e.g. lichens and beetles (Ranius & Nilsson 1997; Ranius *et al.* 2008; Ranius *et al.* 2009). Because of the importance of old tree structures, the risk of an extinction debt for old tree-associated species increases with increased age gaps between oak cohorts – therefore a relatively frequent regeneration is important for the ecological continuity. For example, an oak usually develops hollows at an age of 200–300 years (Ranius *et al.* 2009).

A recent oak decline has been noticed and studied in Europe during the last few decades (Jensen *et al.* 2012; Mitchell *et al.* 2019). This decline in combination with failure in natural regeneration (Jensen *et al.* 2012) could threaten not only oak populations, but also oak-associated species (Mölder *et al.* 2019). The introduced fungal Dutch elm disease (DED, *Ophiostoma spp.*) has been known occurring in Europe since the early 1900's and has since caused severe decline in many populations of different elm species (*Ulmus* spp.) in Europe. A similar large-scale decline, ash dieback, caused by another introduced fungal pathogen, *Hymenoscyphus fraxineus*, can be seen in European ash (*Fraxinus excelsior*) populations in Europe (Hultberg *et al.* 2020). The decline in ash and elm populations in Europe has made the continuity of oak even more important for supporting species depending on old hardwood trees as a habitat.

1.2. The study area

Dalby Söderskog is a eutrophic temperate mixed broadleaved forest located in the county of Skåne (Scania) in southern Sweden (55°40'34"N 13°19'48"E). The forest has been a national park since 1918 and with its 36 hectares it is the smallest national park in Sweden. Dalby Söderskog has probably been forested for as long as broadleaved forests have existed in the area – around 8000 years (Blomberg 2018).

The tree species that historically have been dominating the forest canopy are wych elm (*Ulmus glabra*), European ash, European beech (*Fagus sylvativa*) and pedunculate oak (Lindquist 1938). After the protection of the forest, elm gradually became the dominant tree species – until DED (Dutch elm disease) struck the population in the 1980's and ash became the most dominant tree species in the upper tree layer (Brunet *et al.* 2014). Now ash dieback has reached the forest and ashes are falling out of the upper canopy layer, creating gaps and increasing the amount of light to the forest floor (Ruks 2020). Previous studies also show that there has been a linear decline in the number of living oak stems from 1935 until 2011 (Lindquist 1938; Lindgren 1971; Brunet *et al.* 2014).

Unlike the plains of Skåne, areas around and on Skåne's horsts were forested until medieval times. Now, Dalby Söderskog is one of few forests on fertile, loamy soil with long continuity in southern Sweden (Blomberg 2018). There is an embankment with a ditch surrounding about 18 hectares in the southeastern part of the forest. The embankment and ditch has been interpreted as an enclosure for a medieval royal hunting park, where deer were likely kept (Andrén 1999). After that, the forest has been grazed by domestic animals since late medieval time – in 1465, 60 horses were kept in the former hunting park by the nearby Dalby monastery (Blomberg 2018). During late 1500's, the grazing decreased while cuttings increased.

In the 1880's, trees from the 1500's and 1600's were cut in the forest – these were probably among the most extensive cuttings in the history of the forest and the cuttings were criticized by the local botanical association. During 1914–16 new cuttings took place – this led to even stronger reactions from local nature conservation and botanical associations and in 1916 a decision was made to stop all cuttings. This was the start for the forming of a national park that was established in 1918 (Lindquist 1938). Domestic animals disappeared from Dalby Söderskog in the end of the 1800's, but the establishment of a national park in 1918 meant a definite end for future domestic grazing and most cuttings. Some cuttings have been carried out for nature conservation purposes from the 1950's to the 1990's, elms affected by DED were cut between 1988 and 1997 and the trails, the embankment and a few other areas are regularly maintained to be kept open or semi-open (Lindquist 1938; Brunet & von Oheimb 2008). Apart from this, the forest has been left for free succession since its protection.

1.3. Previous studies

Few forests in Europe have been subject to several repeated vegetation surveys like Dalby Söderskog has (Verheyen *et al.* 2017). Thanks to recurring studies and surveys during more than a century, there are plenty of data for long-term vegetation studies. This thesis focuses on oaks with a dbh (stem diameter at breast height) of 10 cm and more. The earliest survey with comparable oak data was conducted in 1916 and after that, in 1935 (Lindquist 1938), 1970 (Lindgren 1971) and 2011 (Brunet *et al.* 2014). Other studies on Dalby Söderskog that are referred to in this thesis are Finnström (2016) and Ruks (2020).

1.4. Aims for this thesis

This thesis aims to describe and analyse the development of the oak population in Dalby Söderskog 2011–2020 by focusing on trees >10 cm dbh, and comparing the results with previous surveys. Although only nine years have passed since the last survey, a new inventory has become ecologically relevant due to rapid disease-related changes in the ash and elm populations which, in turn, may affect both the vitality of old oaks and the conditions for oak to regenerate.

The population is assessed on the basis of three aspects:

1. The number and dbh distributions of living stems (>10 cm dbh), and of standing dead stems (>30 cm dbh that had died since the 2011 survey by Brunet *et al.* (2014)).
2. Mortality and vitality of the population – with three possible scenarios as a starting point:
    - I. The mortality rate of the oak population has increased as a result of an aging population
    - II. The mortality rate has decreased as oak crowns have been released from competing elm and ash
    - III. The mortality rate of the oak population is stable
3. The spatial distribution of the oak population.

2. Method and materials

2.1. The 2020 survey

Oaks >10 cm dbh were surveyed, including all living trees and standing dead oaks that had died between 2011 and 2020. The data collected for each tree was: dbh, coordinates and vitality (Tables 1 and 2). Dbh was measured with tape measure at 130 cm above the ground. On trees with multiple stems, stems were measured individually if the forking was below dbh, and notes were taken regarding multiple stems. Coordinates were collected in coordinate system RT90 using a Garmin GPSMAP 60CXs.

Table 1. Vitality classes and assessment criteria for the inventory of oaks >30 cm dbh in Dalby Söderskog 2020.

1	Vital, healthy, *dominant* tree with a large, airy crown
2	Vital, healthy tree with somewhat reduced but fairly airy crown
3	Tree with reduced vitality due to stem damages, large dead branches or severely reduced crown – may still live for several decades
4	Dying tree with small number of living branches
5	Dead tree

In denser parts of the forest, brass nails were used as markers to minimize the risk of surveying the same tree twice.

All standing oaks >30 cm dbh were surveyed by the author of this thesis (n=552 living and 26 dead trees). Oaks with dbh between 10–29 cm (n=48 trees) were surveyed by Jörg Brunet. Instead of vitality, competition from other vegetation was assessed for oaks <30 cm dbh. Only direct competition from surrounding shrubs and young, slightly taller trees, was considered. The competition scale ranged from 1 to 4 (Table 2).

Coordinates, dbh and vitality for all standing trees in the 2011 survey were imported to ArcMap, with dead and living individuals in separate data sets. This made it possible to find and identify individual trees in field with ArcGIS Collector. A layer with coordinates, dbh and vitality class for the 2020 survey was regularly updated in order to keep track on which areas had already been surveyed (see Appendix C for GIS flowchart) and to further minimize the risk of surveying the same tree twice if any of the markers had been removed or fallen off.

Table 2. Competition classes and criteria for competition assessment 10–29 cm dbh in the 2020 oak survey of Dalby Söderskog.

1	At least 75% of the tree's crown periphery is free from competition.
2	33-75% of the tree's crown periphery is free from competition.
3	0-33% of the tree's crown periphery is free from competition, but the tree has free growing space upwards.
4	The crown is shaded by taller surrounding crowns.

2.2. Analysis

2.2.1. DBH class distribution

The 2020 survey is mainly compared to the previous survey in 2011 by Brunet *et al.* (2014) and effects that changes may have on the population are discussed. dbh classes are divided in steps of 10 cm (10–19, 20–29 etc.) and comparisons with previous surveys are based on these classes. Basal area (BA) ($0,0001*3,142*(dbh/2)^2$) is calculated for each stem, these BA's are then summed up and divided by 36 (the study area in hectares) to get BA/ha. Average and median dbh values are presented for dbh classes >10 cm and >30 cm separately.

2.2.2. Vitality and mortality

Mortality is compared to results in previous surveys using dbh classes in 10 cm steps. Dbh classes >10 cm and >30 cm are presented separately for comparison.

2.2.3. Spatial distribution

ArcMap 10.8 was used to map coordinates for all surveyed stems and to graphically show the distribution and density of oak stems within the study area. See Appendix C for details.

3. Results

3.1. DBH class distribution 2020

3.1.1. Living oaks

The total number of living oak stems with a dbh of 10 cm or more was 600 (16,7 stems/ha) (Figure 2; Table 3), compared to 624 stems (17,3 stems/ha) in 2011 – which means a reduction of 4,2%. Corresponding reduction of BA is 5,0% as BA was 8,8 m^2/ha in 2011 and 8,4 m^2/ha in 2020. The only dbh classes where the number of living stems has increased are the smallest (10–29 cm) and the largest (90–99 and 110–139 cm), in all other classes the number of stems has decreased (Table 3).

The average dbh for stems >30 cm has increased from 78,6 cm in 2011 to 82,2 cm in 2020. With dbh classes 10–29 cm included, the average dbh for 2020 is 76,6 cm – no stems in dbh classes 10–29 cm were present in 2011. The median dbh among trees >30 cm dbh has increased from 78 cm in 2011 to 81 cm in 2020. With dbh classes 10–29 cm included, the median dbh for 2020 is 79 cm. The largest oak in the 2020 survey had a dbh of 135 cm (134 cm in 2011).

The distribution of dbh classes is now changing from a unimodal distribution towards a bimodal distribution. The gap between dbh classes is moving towards larger classes as the number of living oaks in the mid-size classes is decreasing (Figure 1).

Table 3. Dbh class distributions of living oak stems in 2011 and 2020 surveys of Dalby Söderskog.

DBH class	Number of stems 2011	Number of stems 2020
10–19	0	47
20–29	0	1
30–39	7	5
40–49	22	12
50–59	61	38
60–69	107	95
70–79	142	110
80–89	116	110
90–99	94	97
100–109	43	41
110–119	25	30
120–129	6	12
130–139	1	2
Total n of stems	624	600
Stems/ha	17,3	16,7
BA/ha	8,8 m^2	8,4 m^2

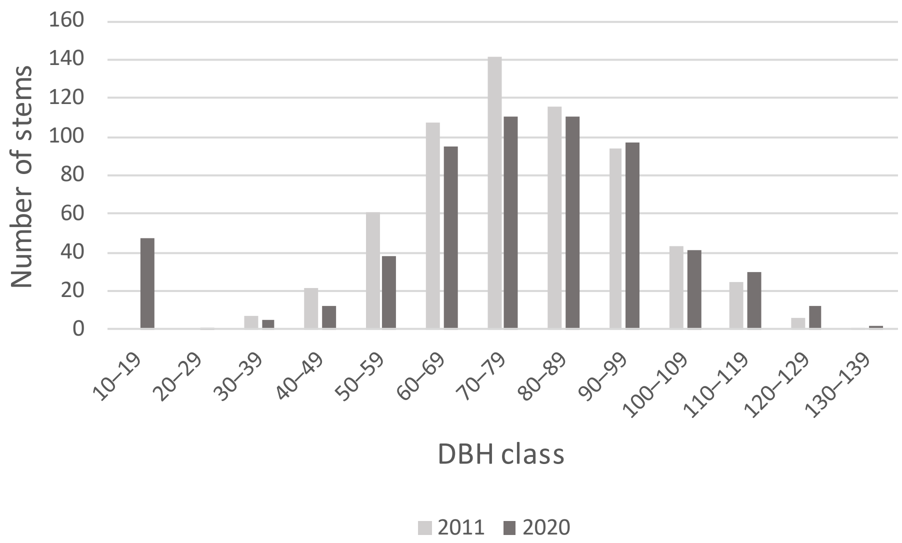

Figure 1. Dbh class distribution for oaks in Dalby Söderskog 2011 (light grey bars) and 2020 (dark grey bars).

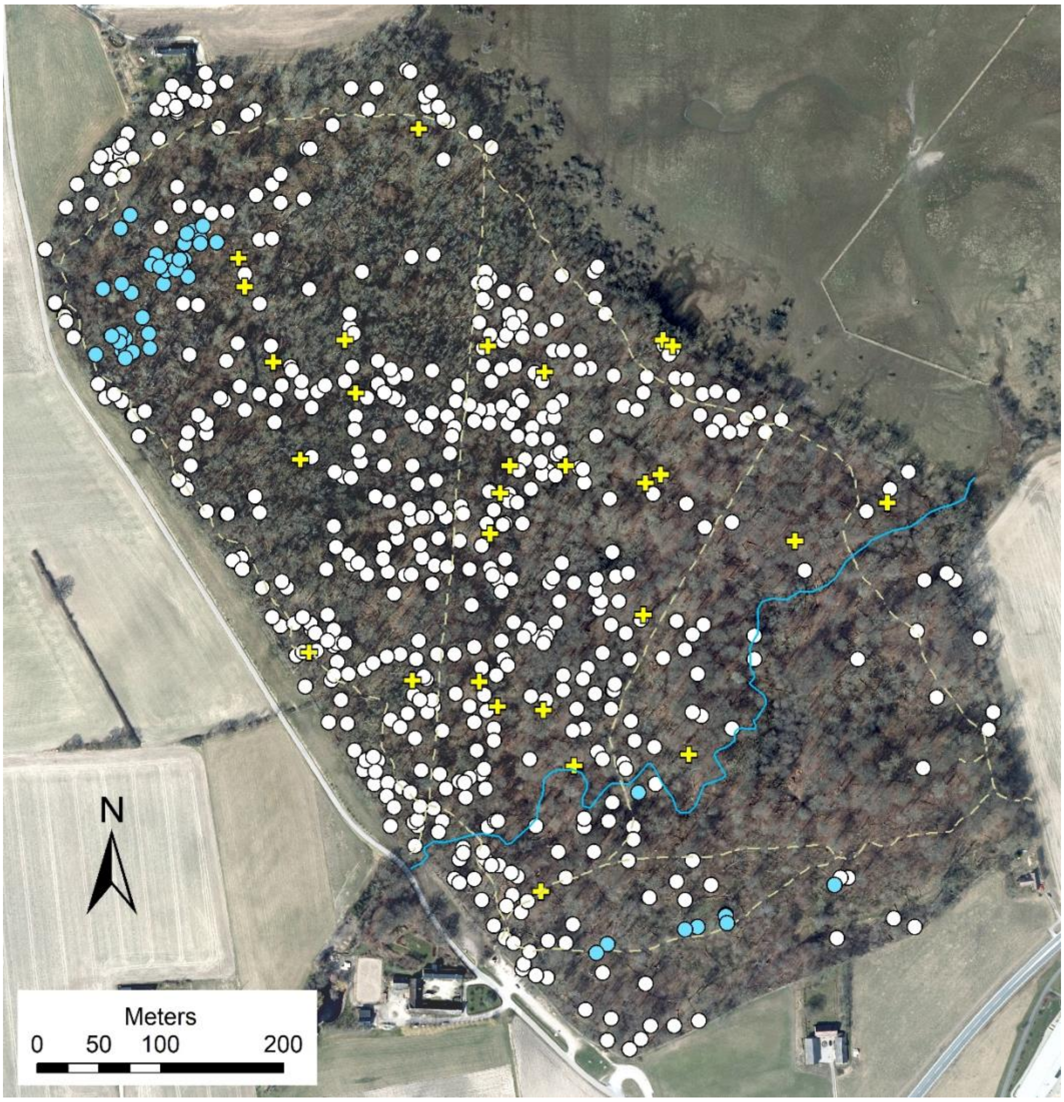

Figure 2. Aerial photo of Dalby Söderskog showing all standing living and dead oaks from the 2020 survey.

Photo: © Lantmäteriet 2019.

3.1.2. Dead oaks

The total number of standing dead oak stems >30 cm dbh in the 2020 survey, that had died between 2012 and 2020, was 26 (Figure 2). The mortality peak is at the 70–79 cm dbh class (Figure 3), which corresponds to the dbh distribution of living stems (Figure 1). Compared to oaks that had died prior to 2012, recently dead oaks have a higher average dbh (68,3 cm in 2011 and 73,9 cm in 2020).

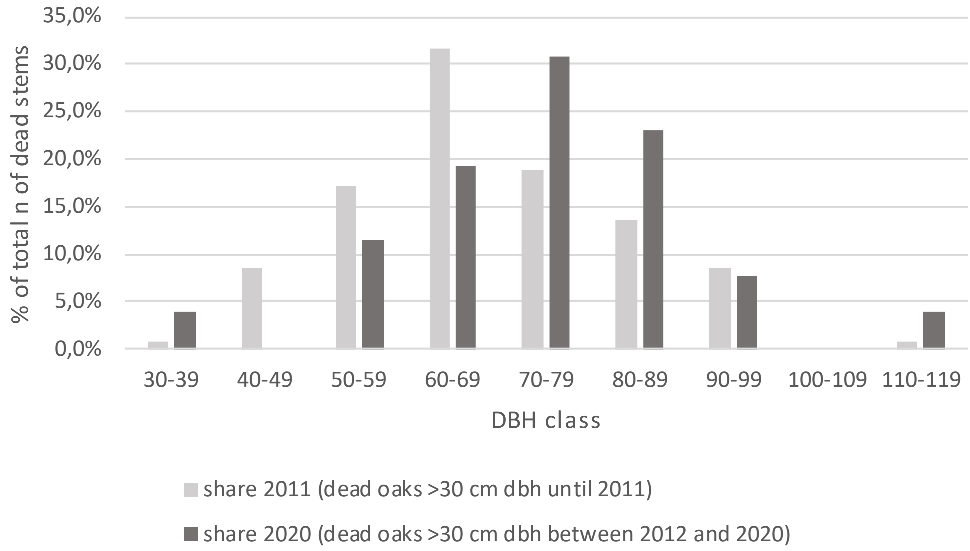

Figure 3. The relative distribution of dbh classes within the total number of standing dead stems >30 cm dbh. Shares of all standing dead oak stems found in 2011 in light grey bars (n=117), stems that had died between 2012 and 2020, in dark grey bars (n=26).

3.2. Vitality and mortality

The number of living oaks >30 cm dbh shows a linear decrease since the 1935 survey (Figure 4). The recent ingrowth of 48 stems in dbh classes 10–29 cm has, however, partly compensated the loss of larger oaks since 2011 (Figure 4). No dead stems <30 cm dbh were found, while 26 standing dead stems >30 cm dbh were found. This leaves 45 stems >30 cm dbh that are assumed fallen between 2012 and 2020.

In dbh classes ≥30 cm, the highest average vitality is found in dbh class 120–129 cm and the lowest average vitality is found in dbh classes 50–69 cm (Figure 5). The competition assessment 2020 for dbh classes 10–29 cm resulted in 4 stems in class 1, 33 stems in class 2, 11 stems in class 3 and no stems in class 4 (see Table 2 for criteria).

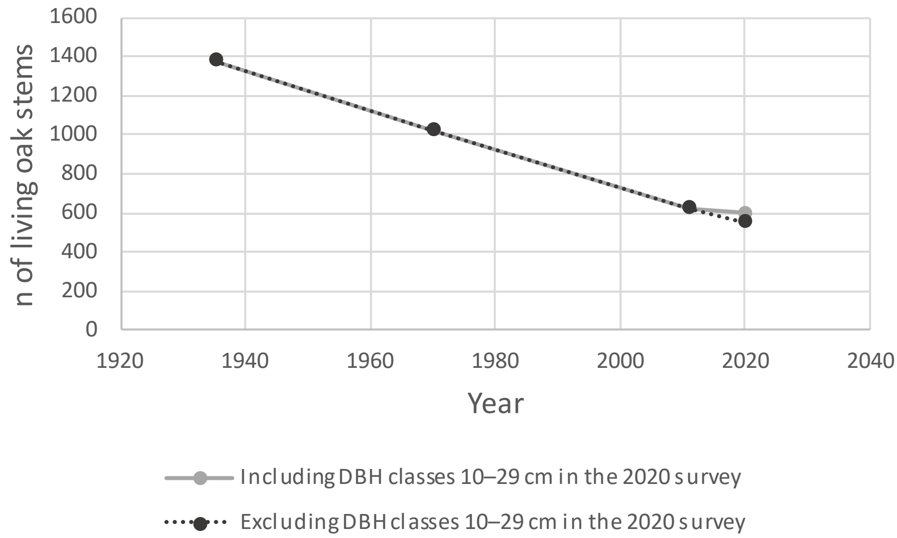

Figure 4. Changes in the number of living oaks >10 cm dbh (solid line) and >30 cm dbh (dashed line) in Dalby Söderskog between 1935 and 2020. See Appendix A for details.

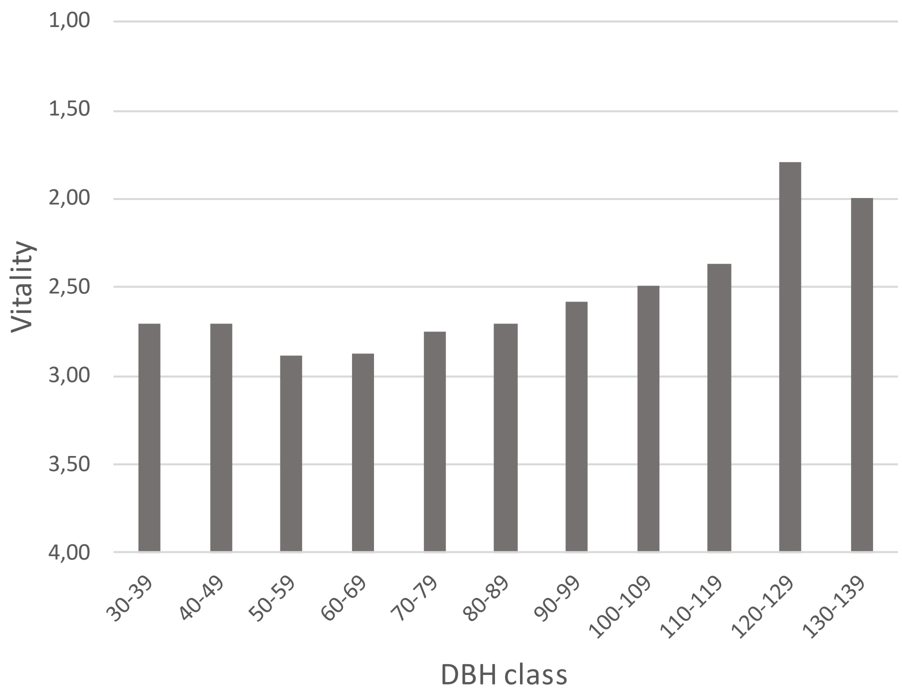

Figure 5. Average vitality in dbh classes in the 2020 survey. 1=very high vitality, 4=very low vitality (see Table 1 for classification details)

3.3. Spatial distribution

Oaks occur in most parts of the forest, but the distribution is un-even. Some parts have higher densities (the centre and the western edge) and some parts largely lack oaks >10 cm dbh, in particular the southeastern part of the forest. Out of the 48 stems in dbh classes 10–29 cm, 40 stems are clustered in the north-west and 8 stems are standing in the south. There seems to be no clear pattern in the spatial distribution of dead stems in relation to the distribution of living stems >30 cm dbh (Figure 6).

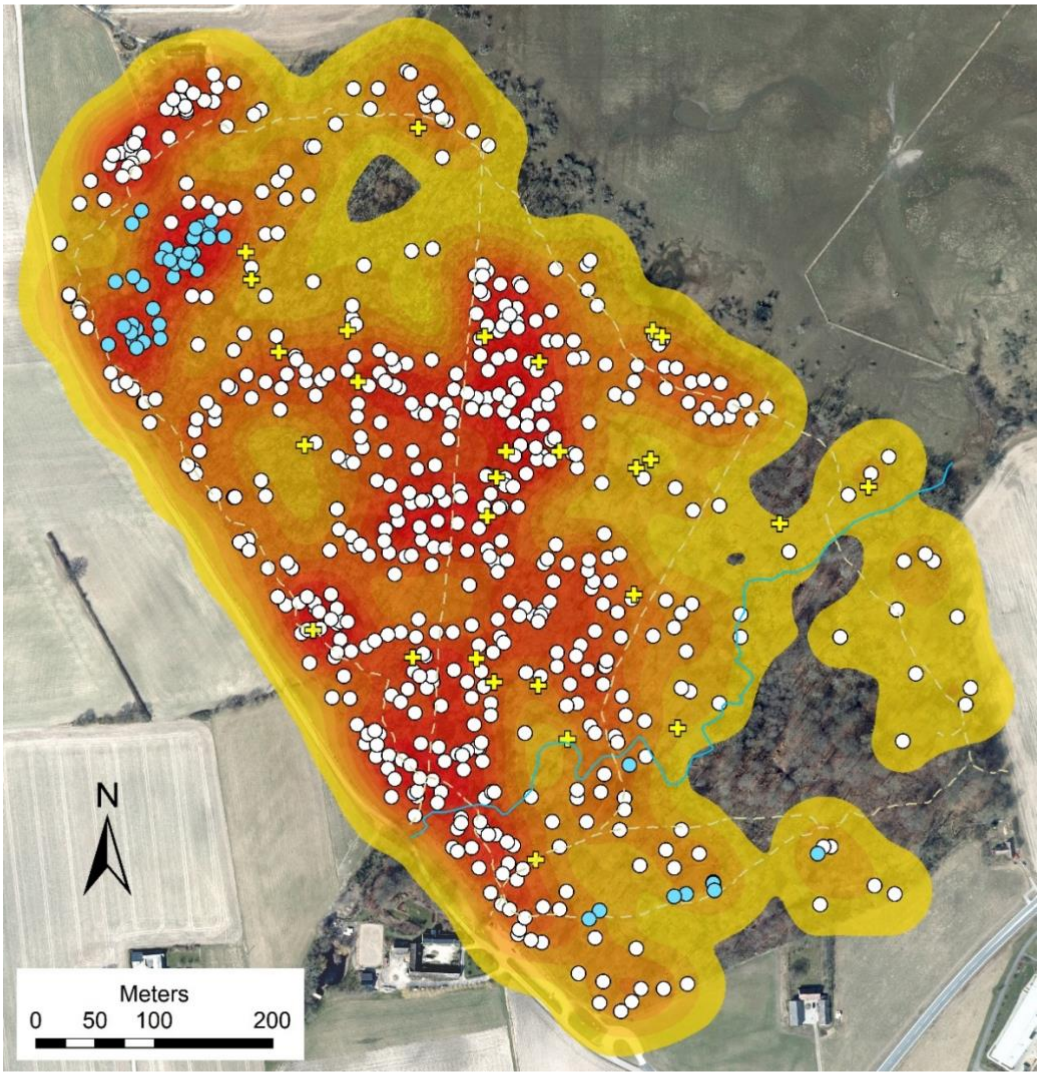

Figure 6. Densities of living oak stems >10 cm dbh in Dalby Söderskog 2020.

4. Discussion

4.1. DBH distribution

The peaking dbh class has been moved towards larger classes since the 2011 survey, which is explained by a population that is growing older without successful regeneration in a long time. The development towards larger mean dbh sizes of oaks in Dalby Söderskog has been going on ever since 1935 and almost all the oak regeneration surveyed in 1935 by Lindquist (1938) had died in 1970 (Lindgren 1971). The population is thus aging and the total number of living stems >10 cm dbh is still decreasing. However, the results also show that a new regeneration is taking place in the forest – this is the first substantial regeneration since the 1935 survey by Lindquist (1938). Though, due to unsuccessful regeneration during many years, there is a gap between the smallest and the mid-sized dbh classes, which is moving the population's dbh distribution from unimodal to bimodal. In a survey in 2015, Finnström (2016) found 784 oak saplings with a height of 1,3 m or more in Dalby Söderskog. Finnströms results indicate that the new ingrowth into the dbh classes 10–29 cm in the 2020 survey is probably just a hint of what is to come. The decreased vitality among elm and ash means a forest with more light to the ground. The conditions for the new regeneration to succeed is therefore better than during the last century. In fact, the current cohort of young oaks may be the first to reach the upper canopy since the early 1800s (Lindquist 1938).

With the large generation gap in the oak population of Dalby Söderskog, the decline among old oaks will in time affect organisms (e.g. lichens, fungi and beetles) that are dependent on old tree structures (Ranius & Jansson 2000; Norden *et al.* 2004; Ranius *et al.* 2008; Milberg *et al.* 2016). Until the gap between dbh classes is closed, organisms hosted by old living oaks will have to find habitat on other tree species – probably beech, since large elms are gone and the ash is decreasing rapidly – or in nearby protected forests with oak such as Dalby Norreskog and Billebjer. The current seed producing oak trees in the Dalby Söderskog will be dead within a century if the current mortality rate remains stable. Therefore, these locations could also become important seed sources if the seed production of today's regeneration will not be sufficient in the coming century. All areas with sufficient levels of light to the ground in Dalby Söderskog will be potential locations for oak regeneration since seeds are spread and buried by both jays, squirrels and rodents. Jays can spread seeds several hundred meters (Kollmann & Schill 1996), which enables recruitment from the mentioned nearby forests.

The ash would have been able to fill the generation gap and host a number of oak-associated species until the oak generation gap was closed if it was not for the introduction of ash dieback (Ruks 2020). Elms (*Ulmus* spp.) and oaks (*Quercus* spp.), followed by beech (*Fagus sylvatica*), are the most important alternative host tree genera for ash-associated species (Hultberg *et al.* 2020). Since large elms are practically gone from Dalby Söderskog (Brunet *et al.* 2014), there is now a new additional perspective on the importance of the conservation of old oaks.

4.2. Vitality and mortality

Out of the three possible scenarios regarding mortality that were presented in the aims for this thesis, results show that scenario (iii) is true – if stems <30 cm dbh are excluded: the mortality rate among oaks >30 cm dbh is unchanged since 1935 (Figure 4). One explanation to this could be that scenarios (i) and (ii) compensate for each other – in some areas the mortality rate has increased due to competition while in other areas the mortality rate has slowed down when oaks are being released from competition when elms and ashes die. As a large part of the oaks >30 cm dbh now are 300-340 years old according to tree-ring measurements of sample oaks by Lindquist (1938), also natural age-related mortality may increase with time, independent of competition effects. The new ingrowth of 48 trees in dbh classes 10–29 cm does not yet compensate for the mortality and therefore the number of living stems is still decreasing.

The mortality rate among oaks >30 cm dbh is still unchanged – but the number of stems in the largest dbh classes (>110 cm dbh) has increased (Figure 1). No dead stems in dbh classes 10–29 cm were found and the 2015 survey conducted by Finnström (2016) and preliminary results from a survey conducted by Brunet (unpublished) show that the ingrowth of stems into the 10–29 cm dbh classes could balance the mortality to regeneration ratio within a few years. The successful oak regeneration indicates that the competition for light has decreased, which theoretically also could give larger trees with low vitality a chance to recover, now that they are released from competition in the upper canopy layer (Lariviere *et al.* 2021).

If individual oaks are still losing vitality due to competition, active crown release by either cutting or pruning adjacent trees could be an important measure to give mid-sized oaks time to develop old tree structures that are important for biodiversity and to prolong the lives of the largest oaks (Götmark 2013; Lariviere *et al.* 2021). Active crown release should probably be considered only when beech is the competing species in the southeastern parts of the forest (cf. appendix B, Ruks

2020), since both elm (endangered) and ash (critically endangered) are on the national 2020 Red List of Swedish Species list (Artdatabanken 2020) and are rapidly decreasing in Dalby Söderskog. The beech, on the other hand, is still common and has a rather even dbh size distribution (Brunet *et al.* 2014). A competition survey on old oaks would be necessary before any crown release-measures are done. The main focus, though, should be to monitor the new regeneration of oak and, if needed, to release young stems from competition to ensure a sufficient survival rate.

In addition to competition from shading by other vegetation, the regeneration failure of oak could depend on factors that have not been noticed to the same extent. Demeter *et al.* (2021) suggest that non-native pathogen powdery mildew (PPM, e.g. *Erysiphe alphitoides*, *E. quercicola* and *E. hypophylla*) can decrease oak sapling survival. It is not far-fetched to wonder if PPM, especially in combination with shade, could have prevented oak regeneration in the past, since mildew reduces shade tolerance due to impact on photosynthetic processes (Hajji *et al.* 2009; Marcais & Desprez-Loustau 2014).

4.3. Spatial distribution

The oak occurs in most parts of the forest, but it is unevenly distributed. Higher densities occur in the central parts and along the forest edges to the west. An assumption that can be made is that these areas provided a higher amount of light, both in the past and present (cf. appendix B), which would benefit the oak. The new ingrowth of 48 stems into dbh classes 10–29 cm is mainly taking place in the north-western part of the forest where the previous dense sub-canopy of elm now has died (cf. appendix B). This distribution pattern of oaks 10–29 cm dbh in 2020 is similar to the distribution of oaks <10 cm dbh found in 2011 (Brunet *et al.* 2014) and 2015 (Finnström 2016).

All tree species that grow in the study area today have been documented since at least the 1500’s, but the distribution patterns have varied (Lindquist 1938). It seems, according to Lindquist (1938), that oak and beech have a longer continuity in the upper canopy layer than elm and ash. The medieval forest is described by Lindquist (1938) as a sparse forest of oak and beech, with a dense understorey of hazel. Furthermore, Lindquist (1938) means that heavy cuttings in the early 1800’s contributed to an increased number of elms in the forest. Lindquist (1938) describes that today’s generation of oak, in the central parts of the forest, grew up without competition from elm, but already in the 1930’s it suffered from increasing competition, and oak has not been able to regenerate under these circumstances (see Ruks (2020) for current spatial distributions of the main tree species and Appendix B for ditto in 1935).

4.4. Conclusions

Just like many other oak populations in temperate Europe, the oak population in Dalby Söderskog has failed to regenerate since the protection of the forest (Bernadzki *et al.* 1998; Wolf 2011; Rohner *et al.* 2012). The canopy disturbance needed for oak to regenerate was removed when the forest was formally protected and the grazing by domestic animals ceased (Lindquist 1938). The mortality rate among older trees has been constant since 1935 and in less than a century from now, most oaks that today are >30 cm dbh will probably be dead. With time, this will lead to a lack of old, living habitat trees. It is uncertain whether any trees will have time to develop old tree structures before today's old trees are dead, considering the stable mortality of the population. Another possibility could be that the low vitality of the mid-sized oaks leads to earlier development of hollows and certainly dead wood, but their time alive will still be limited compared to that of the larger old oaks of today's forest.

As an effect of DED and ash dieback, there is now a new oak regeneration in Dalby Söderskog when parts of the forest gets more light to the ground. The new ingrowth of 48 stems into dbh classes 10–29 cm does not yet compensate for the current mortality, but preliminary and promising results show that the regeneration could compensate for the mortality within a few years.

When today's old, living habitat trees are dead, organisms depending on old living tree structures such as coarse bark and hollows, will probably have to rely on either other tree species or nearby oak populations such as Dalby Norreskog and Billebjer until younger trees of Dalby Söderskog have started to develop these structures. These nearby forests will not have the possibility to host organisms, but could become important seed sources if there will be a lack of seed producing oaks in Dalby Söderskog in the coming century. Meanwhile, beech will have to carry much of the biodiversity tied to living trees since old elms are gone due to DED and ash is rapidly decreasing due to ash dieback. Furthermore, both elm, ash and oak will provide plenty of dead wood and support organisms depending on dead and dying wood (Mitchell *et al.* 2019; Hultberg *et al.* 2020).

One focus for nature conservation in the coming century should be to keep mid-sized and old oaks alive for as long as possible to support the biodiversity of the forest. To judge the necessity of crown release, a competition assessment on larger oaks would be required.

Another focus for nature conservation should be to monitor and possibly actively promote the new regeneration of oaks by removing or pruning competing vegetation to ensure the development of future cohorts of oak.

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Appendix A: DBH distributions 1935–2020

In Table 4, dbh distributions in surveys from 1935 (Lindquist 1938), 1970 (Lindgren 1971), 2011 (Brunet *et al.* 2014) and 2020 are presented.

Table 4. Dbh distributions of oak stems in Dalby Söderskog 1935–2020.

DBH class	1935	1935	2011	2020
10–19	27	11	0	47
20–29	20	15	0	1
30–39	146	34	7	5
40–49	193	102	22	12
50–59	380	210	61	38
60–69	354	191	107	95
70–79	177	187	142	110
80–89	78	146	116	110
90–	5	125	169	182
TOTAL	1380	1021	624	600
Stems/ha	38,3	28,4	17,3	16,7

Appendix B: Previous distributions

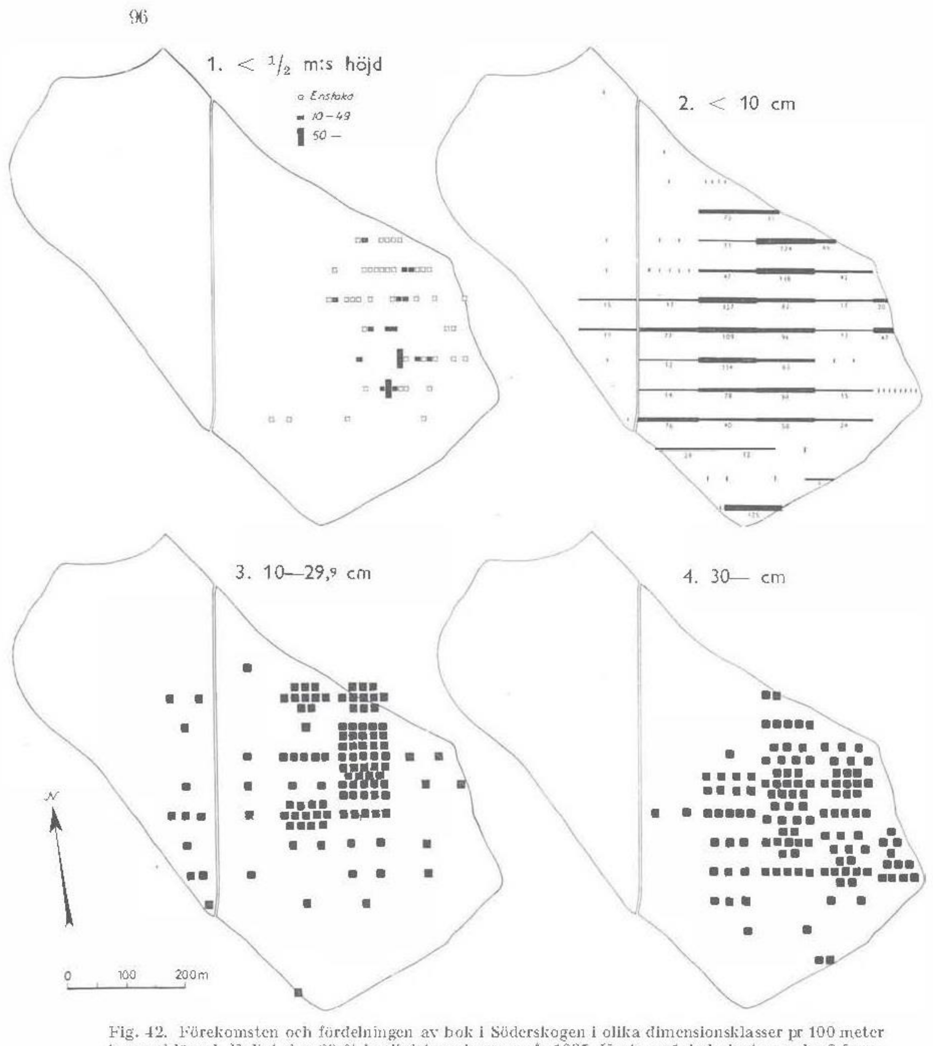

Fig. 42. Förekomsten och fördelningen av bok i Söderskogen i olika dimensionsklasser pr 100 meter taxerad längd. Enligt den 20 %-iga linjetaxeringen av år 1935. Karta nr 1: bokplantor under 0,5 meters höjd (1—10 år) taxerade utefter 1×10 meters bälten. Öppen kvadrat betecknar enstaka bokplantor inom bältet, fylld kvadrat 10–49 plantor pr bälte och fylld vertikal stapel över 50 plantor pr bälte. Karta nr 2: bok under 10 cm i brh p.b. (20—40 år); karta nr 3: bok mellan 10 och 30 cm i brh p.b. (omkring 60 år) och karta nr 4: bok över 30 cm i brh p.b. (omkring 100 år och äldre). Se vidare texten till fig. 38.

Das Vorkommen der Buche in Söderskog und ihre Verteilung auf verschiedene Dimensionen pro 100 m taxierter Länge. Laut der 20%igen Linietaxierung 1935. Karte Nr. 1: Buchenpflanzen unter 0,5 m (1—10 jährig) taxiert längs 1 × 10 m Streifen. Offene Quadrate bezeichnen einzelne Buchenpflanzen innerhalb des Streifen, gefüllte Quadrate 10—49 Pflanzen und vertikale Stapel über 50 Pflanzen pro Streifen. Karte Nr. 2: Buchen unter 10 cm in Brusthöhe, berindet (20—40jährig); Karte Nr. 3: Buchen zwischen 10 und 30 cm in Brusthöhe, berindet (ca. 60jährig) und Karte Nr. 4: Buchen über 30 cm in Brusthöhe, berindet (etwa 100jährig und älter). Vergl. weiter den Figurentext 38.

Figure 7. Occurrence and size distribution of beech (Fagus sylvatica) in Dalby Söderskog 1935 from Lindquist (1938). Top left: stems <50 cm in height (1-10 years). Top right: Stems <10 cm dbh (20-40 years). Bottom left: stems 10–29,9 cm dbh. Bottom right: stems >30 cm dbh (around 100 years and more).

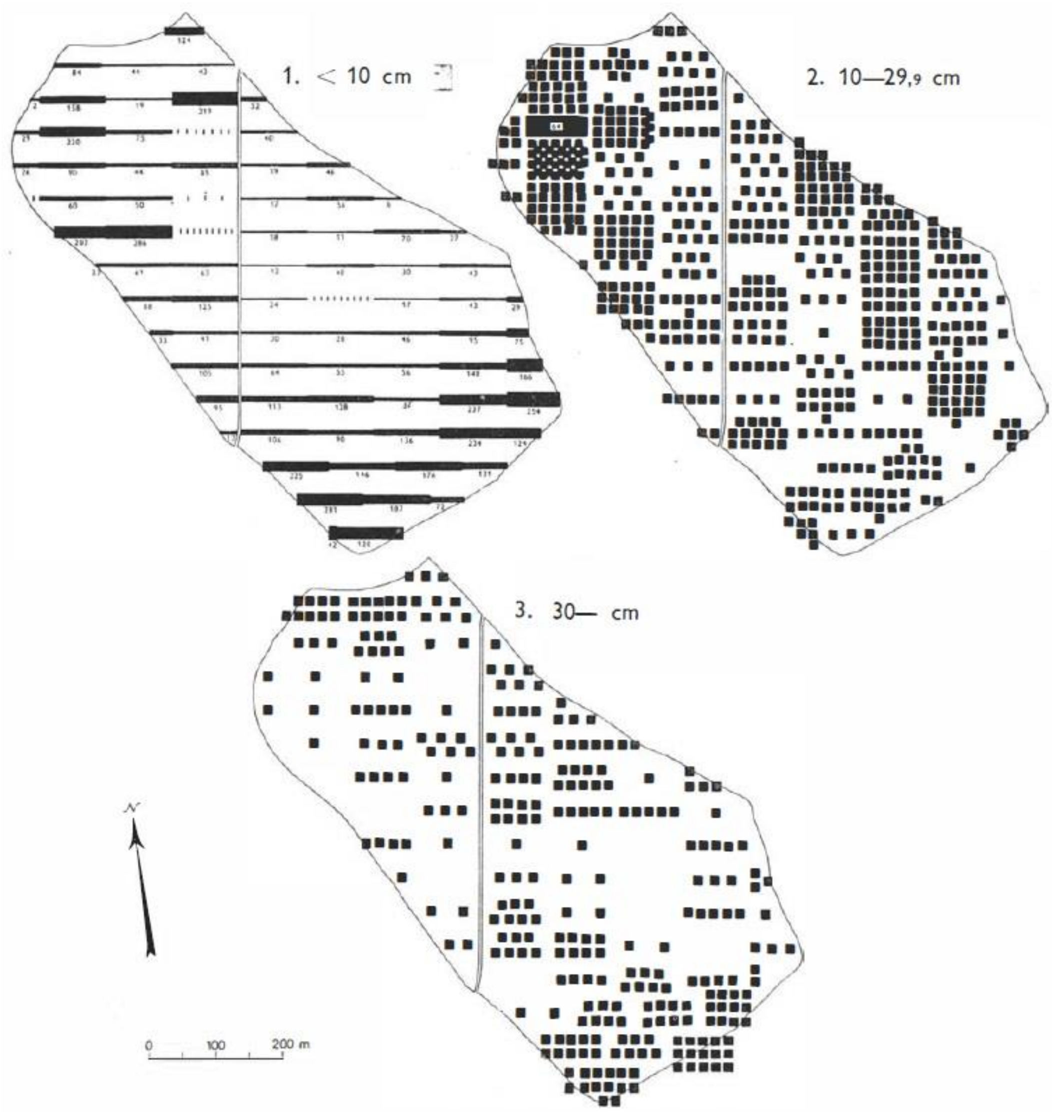

Fig. 48. Förekomsten och fördelningen av alm i Söderskogen i olika dimensionsklasser pr 100 meter taxerad längd. Enligt den 20 %-iga linjetaxeringen av år 1935. Karta nr 1: alm under 10 cm i brh p.b. (20—40 år), nr 2: alm mellan 10 och 30 cm i brh p.b. (omkring 70 år), nr 3: alm över 30 cm i brh p.b. (omkring 100—200 år). Se vidare texten till fig. 38.

Das Vorkommen der Ulme in Söderskog und ihre Verteilung auf verschiedene Dimensionsklassen pro 100 m taxierter Länge. Laut der 20 %igen Linietaxierung im Jahre 1935. Karte Nr. 1: Ulmen unter 10 cm in Brusthöhe, berindet (20—40jährig), Nr. 2: Ulmen zwischen 10 und 30 cm in Brusthöhe, berindet (ca. 70jährig); Nr. 3: Ulmen über 30 cm in Brusthöhe, berindet (ca. 100—120jährig).

Figure 8. Occurrence and size distribution of elm (Ulmus glabra) in Dalby Söderskog 1935 from Lindquist (1938). Top left: stems <10 cm dbh (around 20–40 years old). Top right: Stems 10–29,9 cm dbh (around 70 years old). Bottom: stems >30 cm dbh (around 100–200 years old.

Fig. 38. Förekomsten och fördelningen av ek i Söderskogen i olika dimensionsklasser pr 100 meter taxerad längd. Enligt den 20 %-iga linjetaxeringen av år 1935 (se sid. 76). Karta nr 1: förekomsten av ek under 10 cm i brh p.b. (omkring 20—40 år); nr 2: ek mellan 10 och 35 cm i brh p.b. (i medeltal omkring 100 år); nr 3: ek över 35 cm i brh p.b. (omkring 200 år). Samtliga längs taxeringslinjerna registrerade träd ha utmärkts på kartorna pr 100 m taxerad längd. De grövre dimensionerna (10—cm) ha utmärkts som kvadrater, under det att inom de klenare dimensionerna antal under tio träd utsatts på kartan med vertikala streck, men däremot antal över tio träd erhållit ett horisontalt streck med uppgift om antalet.

Das Vorkommen von Eichen in Söderskog und ihre Verteilung auf verschiedene Dimensionsklassen pro 100 m taxierter Länge. Laut der 20 %igen Linietaxierung im Jahre 1935. Karte Nr. 1: Eichen unter 10 cm in Brusthöhe (gegen 20—40jährig); Nr. 2 Eichen zwischen 10 und 35 cm in Brusthöhe (durchschnittlich ca. 100jährig); Nr. 3: Eichen über 35 cm in Brusthöhe (ca. 200jährig). Sämtliche längs der Taxierungslinien registrierte Bäume sind kartiert worden, wobei die gröberen Dimensionen als Quadrate bezeichnet sind. Bei der schwächeren Dimension ist die Anzahl von unter 10 Bäumen direkt kartiert worden (vertikale Striche), die Anzahl von über 10 Bäumen ist dagegen auf der Karte mit Ziffern angegeben (horizontale Striche).

Figure 9. Occurrence and size distribution of pedunculate oak (Quercus robur) in Dalby Söderskog 1935 from Lindquist (1938). Top left: stems <10 cm dbh (around 20–40 years old). Top right: stems 10–34,9 cm dbh (around 100 years old in average). Bottom: stems >35 cm dbh (around 200 years old)

Appendix C: GIS flowchart

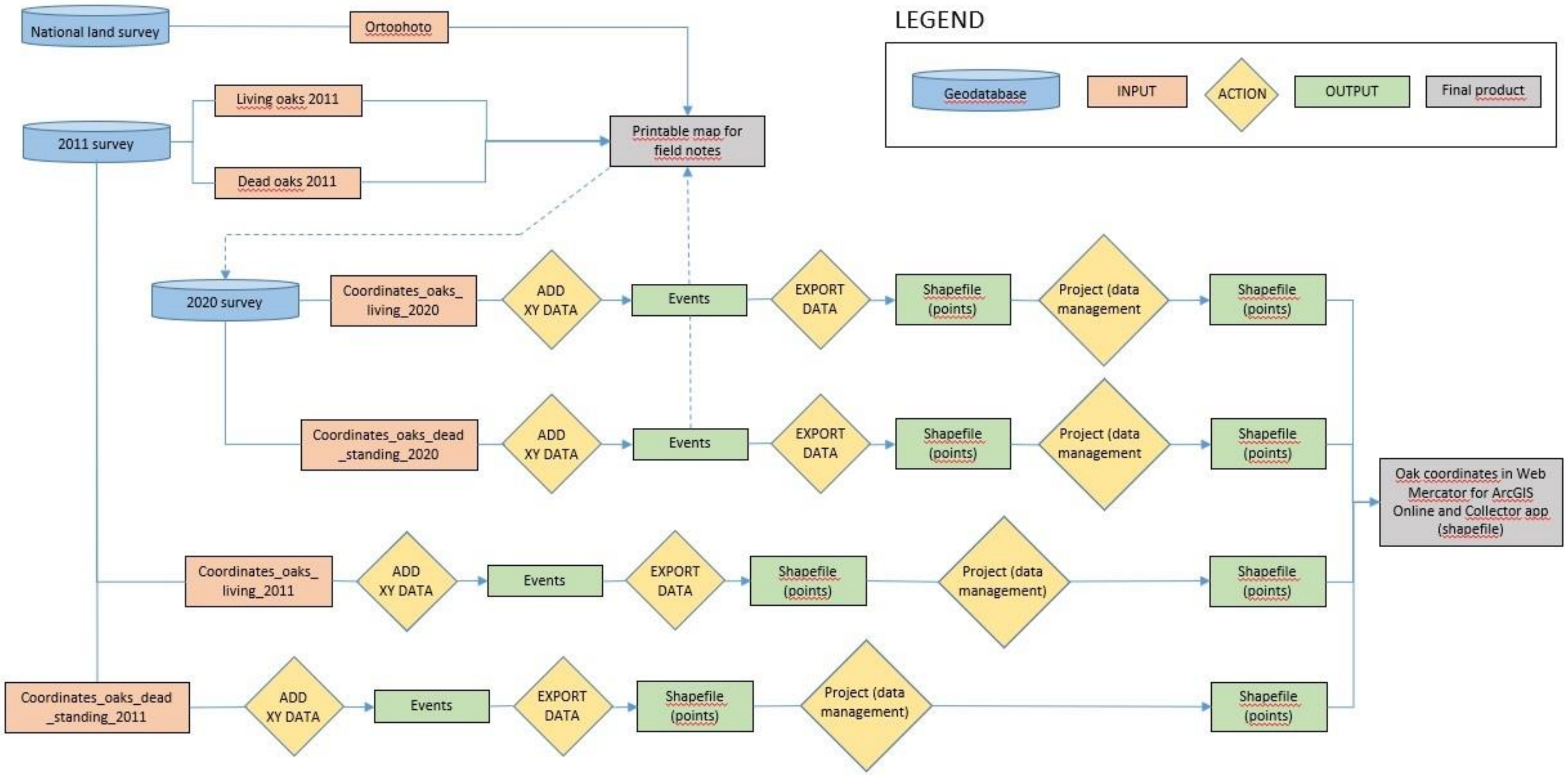

Figure 10. Flowchart for the GIS-supported field work. Both physical and digital maps were used for taking notes and to navigate in the forest. All GIS work was done in ArcMap, ArcGIS Online and ArcGIS Collector.