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Occurrence and management of oak in southern Swedish forests

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Abstract

This article describes the current proportions of forest types with oak (*Quercus robur* and *Q. petraea*) in southern Sweden, provides an overview of oak distribution over time and reviews literature about oak regeneration relevant for the region. Further we discuss silvicultural possibilities to maintain and promote oak in Scandinavia. In Götaland pure oak forest covers 1% of the forest area and mixed forest types with > 10% oak proportion cover approximately 10% of the area. Common types of mixture are spruce-oak and pine-oak forest. Both mixtures are frequent in mature forest, especially pine-oak. Additionally, about one third of spruce-oak mixtures can be found in medium-aged forest.

Intensive management would be necessary to promote single oak trees in old pine stands or spruce plantations, but the proportion of oak in coniferous forest provides some potential to maintain additional oak trees. The distribution of acorns by Jays, enhanced measures against browsing, and the release of single oak trees from competing tree species could help to maintain more oak trees for nature conservation. However, regarding management of oak for timber production, conventional methods are recommended. Planting after clear cutting of coniferous forest, or short shelter periods after mast years in oak stands, are established methods to regenerate pure oak stands. Another possibility to develop mature oak forest are mixed oak-spruce plantations, as traditionally practised in a small region in southern Sweden. The different approaches of oak management in Sweden were presented in April 2012 on the annual meeting of the section silviculture of DVFFA (German Union of Forest Research Organizations) in Wermsdorf near Leipzig to give an overview and access to recent forest research in Sweden.

Key words: *Quercus*, Sweden, oak silviculture, mixed forest, nature conservation

Introduction to southern Swedish conditions and forest types

The southern region of Sweden (Götaland, Figure 1) comprises 5 million ha forest. Most forest belongs to the transition zone between temperate and boreal forest. A belt of temperate forest occurs in the south, while more boreal forest occurs in the centre of Götaland (Ahti et al. 1968). A thin belt of very fertile soil in the south is used for agriculture, where forest is very rare. Hornbeam is limited to that area for instance. Further north, forest dominates the landscape. Most common soil types are podsol, cambisol and histosol. Along the west coast nearby Gothenburg, calcareous lithosol types occur (SNA 1990). The 30-year mean annual precipitation varies from 600 mm in the east to 1000 mm in the west of the region, and the mean temperature is -3 and 16 °C in January and July, respectively (SMHI 2009).

Dominant tree species are Norway spruce (*Picea abies*), Scots pine (*Pinus silvestris*), and birch (*Betula pendula* and *B. pubescens*). While spruce comprises 45% of the standing volume in Götaland, the volume proportion of oak (*Quercus petraea* and *Q. robur*) is 4% (YF 2011). Although *Q. robur* is more common, the two oak species overlap considerably in range, forest types and traits, and thus they are not distinguished here. An analysis of national forest inventory data (based on 10 m radius plots) revealed that 1% of the forest area is pure oak forest (Drössler 2010). Other forest types with minimum 10% oak proportion cover additional 4% of the forest area. Depending on definitions of mixed forest, different proportions can be calculated: 3% of the inventory plots contain at least 30% basal area of oak, while 14% of the plots contain at least one single oak tree (Table 1). For beech, the proportion would increase only from 2.5 to 4.5% using the same definitions. In comparison to beech, a considerable proportion of oak occurs in mixture with other tree species. More information on the forest inventory data and calculation method used for Table 1 and 2 can be found in Drössler (2010).

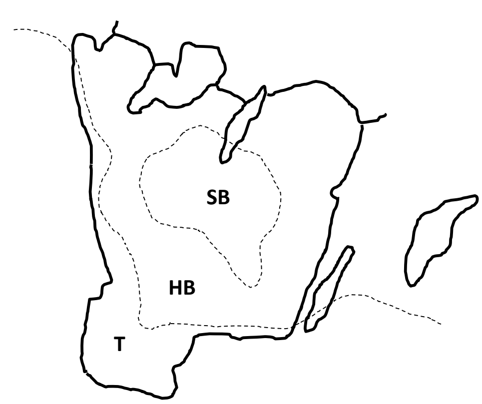

Fig. 1. Map of Götaland (with temperate, hemi-boreal, and southern boreal forest (according to Ahti et al. 1968).

Tab. 1. Percentage of inventory plots with oak and beech using different minimum proportions of the species (from Drössler 2010).

Tree species	Percentage of sample plots where the species occur	Percentage of sample plots where the species accounts for ≥ 10% of basal area	Percentage of sample plots where the species accounts for ≥ 30% of basal area
Oak	13.7	5.5	3.3
Beech	4.4	2.5	2.1

Tab. 2. Area proportion of tree species combinations with oak, number of inventory plots, and standard error. Minimum basal area proportion of each species are 10% (stem number proportion if stand height < 7 m). For tree species combinations observed on 20 inventory plots or less, no representativeness of forest area proportions is guaranteed.

Species	**Forest area** (ha)	**Plot number**	**Standard error**
Oak	49,520	82	5,966
Spruce/oak	39,254	65	5,019
Spruce/birch/oak	21,740	36	3,889
Pine/oak	20,533	34	3,605
Birch/oak	18,117	30	3,294
Oak/beech	15,701	26	3,804
Pine/spruce/oak	15,098	25	3,005
Pine/birch/oak	10,266	17	2,481
Aspen/oak	8,455	14	2,256
Spruce/aspen/oak	7,247	12	2,087
Birch/aspen/oak	6,643	11	2,000
Birch/oak/beech	6,643	11	1,998
Birch/oak/other broadleaves	3,623	6	1,479
Oak/nobel broadleaves	3,623	6	1,478
Oak/lime	3.020	5	1,350
Oak/other broadleaves	2,416	4	1,207
Birch/oak/alder	2,416	4	1,207
Birch/oak/noble broadleaves	2,416	4	1,208
Oak/beech/alder	1,812	3	1,045
Spruce/oak/rowan	1,812	3	1,045
Birch/oak/rowan	1,812	3	1,046
Oak/rowan	1,812	3	1,046
Spruce/oak/beech	1,812	3	1,045
Bare land	*245,184*	*406*	*12,191*
Total	**4,952,000**	**8,200**	

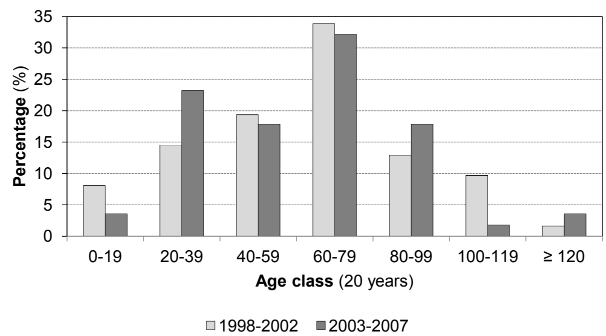

Fig. 2. Relative age class distribution of oak-spruce mixtures (due to limited representativeness per age class, the two independent inventory periods 1998-2002 and 2003-2007 are presented separately).

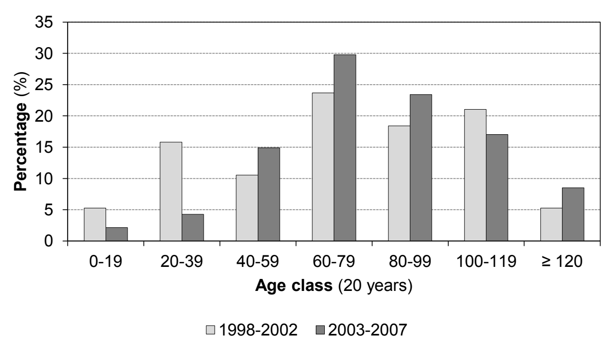

Fig. 3. Relative age class distribution of oak-pine mixtures (due to limited representativeness per age class, the two independent inventory periods 1998-2002 and 2003-2007 are presented separately).

23 tree genus combinations with oak were found in the inventory plots (Table 2). Altogether, these combinations cover 245,000 ha forest in Götaland. For the most common mixed forest types with oak, the inventory provides the best data available to estimate their proportions. Oak is often associated with spruce (about 1% of total forest area), or with spruce and birch. Another common mixture is with Scots pine, which accounts for 1% if other species are included. Oak-spruce mixtures are most frequent in 60-79 years old forest, but rare in very young and very old forest (Figure 2). Oak-pine mixtures are most common in 60-120 years old forest stands (Figure 3). Only 11% of pure oak forest were younger than 40 years. Regardless mixed or pure forest, most oak occurs in older stands.

As in other parts of Europe, oak silviculture in Sweden is usually aiming at high quality timber production, characterized by very intensive management (Carbonnier 1975). However, main production goal is most often sawn timber for flooring and construction wood (Ekström 1987, Nylinder et al. 2006).

Generally, mean annual increment ranges between 4-6 m^3 ha^{-1}, with top heights from 20-26 m after 100 years (Carbonnier 1975). Oak and oak-rich forests often harbour many rare cryptogams, vascular plants and invertebrates, thus the value of oak for biodiversity is very high in Sweden (Jonsell et al. 1998, Ranius and Jansson 2000, Berg et al. 2002, Gärdenfors 2010). To consider conservation values in forests, management planning distinguishes between four types of forest: production forest, production forest with additional conservation measures, reserves with nature management, and reserves without management.

Occurrence of oak in the past and future expectations

According to the succession described by Berglund et al. (1996), oak and lime entered the southern parts of Götaland approximately 9000 years ago and dominated the landscape for several millennia, together with ash and elm on fertile sites. Lindblad et al. (2010) estimated an oak proportion of roughly 25% for temperate forests during the period from 2000 to 0 BC. For hemi-boreal forests, they estimated about 12%, based on separate pollen analyses. However, the proportion decreased during the last 2000 years to 10% respective 3%, after a peak 2000 years ago. Especially during the last 300 years, human influence further reduced the natural decline of oak (Lindblad et al. 2010). One important reason was the cultivation of woodland pasture to arable farm land (Brunet 2006). Slash-and-burn cultivation of forest land more distant from settlements developed often to heathland, which was afforested by conifers during the last century (Nilsson et al. 2005).

Today, the oak decline is also reflected by the lack of regeneration. However, higher survival of oak seedlings was found in coniferous forest than in broadleaved forest (Frost 1997). Götmark et al. (2005a, 2006) found relatively high densities of oak saplings in coniferous forest (ca. 40 saplings with 0.1 to 4.9 cm dbh ha^{-1}). However, the density varied considerably between 0 and 25 saplings ha^{-1} in large areas of central Götaland and 100-500 saplings ha^{-1} in forest close to the coast (Götmark et al. 2006).

Based on future climate scenarios and tree-physiological growth response to temperature and precipitation, future tree species distributions of the potential natural vegetation can be estimated. Therefore, Hickler et al. (2012) parameterized a dynamic vegetation model (LPJ-GUESS) for European tree species, suggesting a future increase of temperate forests in Götaland, while coniferous forest decreases. Starting with the current tree species distribution of managed forests, spruce would almost disappear after 300 years while beech, ash and oak would dominate. The projected oak proportion was 25-30% (Hickler et al. 2012).

Future expectations concerning the development of natural regeneration are less optimistic, especially concerning browsing damages. In temperate forests, 70% of oak seedlings were damaged in a study with 24 stands involved (Götmark et al. 2005b). A similar proportion of oak was browsed in the north of Götaland (Frost 1997). In a multi-layered, hemi-boreal forest with spruce and oak regeneration (browsing damages 2% respective 50%) under pine shelter, a stand growth simulation projected no basal area increase of oak for the next 50 years, due to the fast growth rates of spruce (Drössler et al. 2012). Therefore, browsing damages in combination with more competitive tree species can counteract the effects of climate change, in both temperate and hemi-boreal forest types.

Silviculture in pure oak stands

Establishment

Conventional methods to establish new oak stands are planting or sowing under open land conditions (Birkedal 2010) and natural regeneration in oak stands after a mast year in combination with shelterwood cutting (Almgren et al. 1984, Henriksen 1988, Harmer 1995, Röhrig et al. 2006). Oak stands are generally established by sowing (40-70 kg acorns ha^{-1} according to Skogforsk 2011, or more) or planting 7000-13000 seedlings ha^{-1}. Competing ground vegetation or damages by animals are often reason for failures (Nilsson et al. 1996), thus site preparation could improve early survival and subsequent growth of oak seedlings (Löf et al. 1998, Gemmel et al. 1996). Birkedal (2010) found that the proportion of established seedlings in areas surrounded by broadleaved forest was much lower (< 5%) than in areas with mixed conifer forest surrounding (about 20 - 60%). In addition, the application of mink excrements to seeds under laboratory conditions indicated a large potential to deter rodents from consuming acorns after seeding (Birkedal 2010).

If shelterwood cutting is applied, about 50 oak germs per m² and heavy removals (ca. 50% of standing volume) should assure a successful establishment of regeneration, followed by complete removal in the next 10 to 15 years (see also Matthews 1989, Röhrig et al. 2006).

Thinning and intermediate cuttings

Thinnings of oak in southern Sweden have been investigated by Agestam et al. (1993) and Carbonnier (1975). Usually, 2 or more precommercial thinnings are carried out to remove wolf trees, make a preliminary selection of well-formed trees and ensure enough light to the stand. 50 to 70 future crop trees per ha are marked at the age of 40 to 50 years, for a total of 100 trees per ha with reserves; the selection is based on qualitative aspects and spatial distribution. In fact it is recommended a 12 to 15 m spacing between future crop trees, to allow free crown development. Since development of epicormic branches is often a major problem (Evans 1982), annual pruning is recommended. Commercial thinnings are intended to tend future crop trees and stimulate their crown development. For Götaland two different thinning programmes have been described in Carbonnier (1975). Both start at the time of the future crop tree selections, and are aimed to keep the basal area between 13 and 18 m^2 ha^{-1} (before and after thinning respectively) until 80 years, to stabilise between 18 and 20 m^2 ha^{-1} towards the end of the rotation, between 100 to 150 years. Program A is the traditional management, consisting of light crown thinnings every fifth year, throughout the whole rotation. Program B begins short 5 year intervals between thinnings, which become longer towards the end (15 years), resulting in very heavy thinning. The latter represents the current recommendations for the production of high quality oak timber in Götaland, emphasising the importance of crown release to avoid competition when thinning. Furthermore it is recommended to introduce an understorey of shade tolerant tree species when oaks are about 40 years old, to shade the stem and prevent epicormics emergence. However, very often this recommendation is not followed in practice (but naturally occurring understory is appreciated). Often, a reduction of the number of recommended thinnings can also be observed in practice.

A relevant oak management, similar to Carbonnier's program B, is conducted in Denmark, denominated Bregentved regime. It consists of a series of pre-commercial thinning in young stands among dominant trees to remove undesirable individuals, in combination with heavy thinning among socially intermediate trees while retaining an understory of suppressed oak trees (Rune and Skovsgaard 2007). This is beneficial for the growth as well as the wood quality of potential crop trees. The result are higher diameter increment and a shorter rotation age if compared to Central European tradition, where oak is often thinned lightly and at very regular intervals to achieve a constant annual ring width of no more than 2 mm. More on traditional oak management in Denmark can be found in Henriksen (1988).

In line with the development of the thinning program B by Carbonnier (1975) and the Brengetved regime in Denmark, there is the "free growth" concept described by Jobling and Pearce (1977), Kerr

(1996) and others where free-growth conditions are defined by preserving a space equal to about one half or one quarter of the crown width around the crowns of the selected dominants at all times. The potential of such alternative oak management schemes mentioned here could attract higher interest for forest owners, where high labour costs and very long rotation have always been a disincentive to plant oak. On the contrary, free growth could modify contemporary oak silviculture to cost effectively and optimise the production of high-quality timber. For southern Swedish conditions, the balance between more severe thinning regime and timber quality (together with the demand of specific annual ring width) is currently under investigation.

Silviculture in mixed oak forest

Mixed spruce-oak stands

Oak-spruce mixtures can be developed by retaining large or old oak trees when planting spruce stands (Söderström 2009). Oak might even establish naturally in very young spruce plantations, but the age class distribution in Figure 2 does not indicate this. Aiming for future oak stands, one region in southern Sweden has a long tradition to manage mixed oak-spruce plantations. On fertile sites, different planting pattern are used, usually with future crop oak trees planted with a spacing of 14-15 m, and some additional oak trees (Ståål 1986). Height development of oak is similar to spruce trees during the first two decades (Mason and Baldwin 1995, Linden 2003), but the oak trees require intensive management already after 10 or 20 years (Loginov 2012). Ståål (1986) describes a 40 year-old experimental stand with first thinning at age 20, and 2-4 years thinning intervals until age 40. The advantage of this intensively managed mixture is the short payback period after stand establishment. Positive accumulated net values are possible after 40 years, while it takes 100-120 years in oak monoculture (Linden 2003). Total volume production over a 140 years rotation is estimated to be roughly 20% higher in mixture compared to pure oak stands (Linden 2003). But, only 6% of the mixed oak-spruce plots in Table 2 where located in Blekinge which is the region with this special type of management described by Ståål (1986).

Other possible types of mixture could be natural oak regeneration in mature spruce stands (Götmark et al. 2005a) or mature spruce stands with very old oak trees. The lower proportion of mixtures in younger age classes than in 60-79 years old forest (Figure 2) does not correspond with a large proportion of retention trees since this concept was less common 30 years ago. More likely, there is a noteworthy proportion of oak in typical mature spruce forest. Götmark et al. (2005a) suggested that oak regeneration is stronger and less problematical in coniferous forest (including spruce forest as one specific forest type) than in broadleaved forest. Due to its limited shade-tolerance, oak is not able to establish under closed spruce canopy, but Götmark et al. (2005a) hypothesize that forest edges after clear-cutting combined with Jays may be a major reason for oak colonization of coniferous forest. Unfortunately, natural oak regeneration under such conditions is rarely studied.

Mixed pine-oak stands

Mixtures of pine and oak are common in 60-120 years old forest, and rare in very young and very old forest**.** Götmark et al. (2005a) found oak saplings (0.1-4.9 cm dbh) more often in pine forest than in spruce or birch forest, with an average density of 60 trees ha^{-1} in forest higher than 7 m. Distributed by Jay (*Garrulus glandarius*) or other animals, germinated oaks find good conditions for establishment and growth under pine shelter (Heuer 1996, Schirmer et al. 1999, Kätzel et al. 2005). Considering several decades, the natural regeneration of oak is a first stage of natural succession from pine to broadleaf-dominated forest (Leuschner 1994, Kint et al. 2006, Hickler et al. 2012). Underplanting of oak in pine stands would be a possible way to initiate the succession actively (Kätzel et al. 2005), but is not or rarely applied in Sweden. However, mixtures of oak and spruce under pine can be found sometimes. Growth prognoses for advanced spruce regeneration under pine shelter indicate growth rates for spruce almost two times higher as oak under Swedish conditions. In the example in Figure 4, the simulated basal area proportion of spruce increased by 6.1% in 25 years, while oak increased by 3.5%. Although the validation of Swedish growth models for oak in mixed stands or under shelter is poor, the slow growth corresponds to growth rates observed in pure oak stands on similar sites (Carbonnier 1975). However, silvicultural promotion of single oak trees is usually not considered, which would provide additional possibilities to develop vital canopy trees (as demonstrated for spruce-oak mixtures for instance by Ståål 1986). On the other hand, the slow growth of oak under shelter should not be underestimated. In an example from northeast Poland, pine overstory with a large proportion of oak and other tree species formed diameter distributions similar to Figure 4, but coring oaks revealed the same age as pine (Bielak 2010).

Dispersal and establishment of single oak seedlings in coniferous stands

Considering single oak trees in coniferous forest, the dispersal by Jays can have large influence on seedling establishment (Mosandl and Kleinert 1998). A single Jay can store 4,500 to 11,000 acorns a year, and fly up to 18 km in order to find a sufficiently abundant source

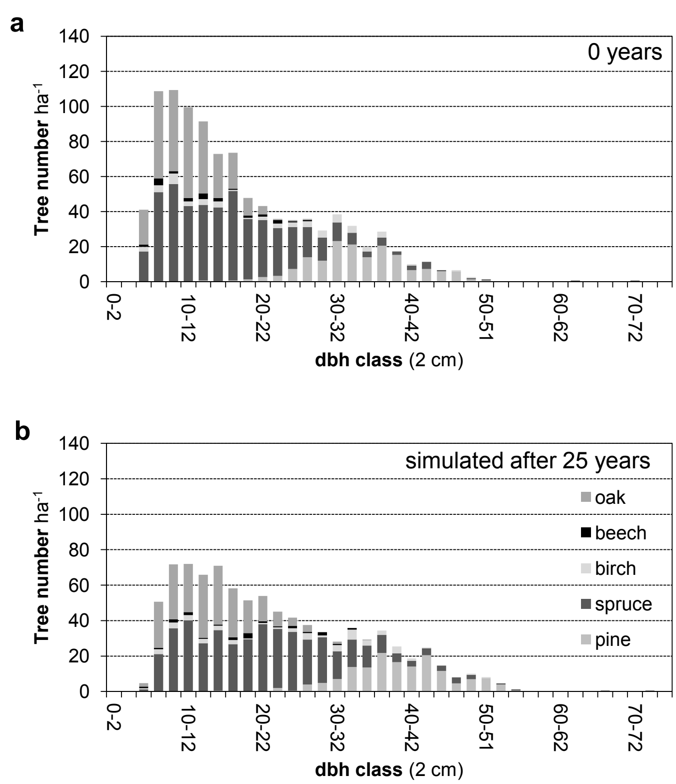

Fig. 4. (a) Current diameter distribution in a very heterogeneously structured stand with pine overstory and spruce in all height layers and oak in the understory, and (b) simulated diameter distribution after 25 years development without management (from Drössler 2012).

of acorns (Cramp 1994, Clayton et al. 1996, cited in Lundberg et al. 2008). For an average distance of 4 km between areas for breeding (spruce) and foraging (oak) and a density of five breeding pairs per km², Lundberg et al. (2008) estimated that one pair of Jays might contribute with 1,000 seedlings per year. That would be equal to 50 new seedlings ha^{-1} a^{-1}. However, accumulated over an unknown time period, Frost (1997) found an average number of 54 oak seedlings ha^{-1} originating from dispersed acorns. On central European mesic sites with average nutrient supply, Mosandl and Kleinert (1998) and Kätzel et al. (2005) reported even 500 to 2,000 oak seedlings ha^{-1} accumulated over time in pine stands. Lundberg et al. (2008) propose a complementary framework to the typical stand management to promote oak regeneration, based on their case study in urban forests of the Stockholm area with a large proportion of oak. Four steps are suggested to deal with multi-scale ecological dynamics:

1. Identify potential foraging and breeding sites.
2. Identify landscape context as distance between foraging and breeding patches.
3. Identify management goals, i. e. increase the amount of spruce to improve breeding conditions.
4. Monitor the results of management by Jay surveys and oak seedling inventories (Lundberg et al. 2008).

Groups of oak trees in pine plantations can be found in eastern Germany ("Mortzfeld´sche Lochbestände") established 100 years ago (Bilke 2005). These might help to test the proposed concept on existing elements in the landscape. Bilke (2005) studied oak regeneration densities in areas with 0-200 m radius from such oak elements and documented more than 2000 seedlings a^{-1} within a radius of 50 m for 38 stands (and > 5,000 seedlings a^{-1} for 26 fenced stands). No effect was detected for 100 to 200 m distant areas (i.e. on the area with radius 200 m, 300 seedlings a^{-1} were counted, and 1,100 individuals if fenced).

Management of oak forests of conservation interest

Many of the oak-rich forests in Southern Sweden are of conservation interest, especially large oak trees provide unique substrates, thus habitats to a diverse range of red-listed cryptogams and invertebrates (Berg et al. 1994, Ranius and Jansson 2000, Götmark 2007). Many of these species-rich oak stands, were once small (> 3 ha) semi-open pastures and fields, that through secondary succession became closed-canopy mixed stands (Götmark and Thorell 2003). Due to crown closure and relative high browsing pressure, recruitment of new oaks to the canopy often is poor (Götmark et al. 2005b). Thus, a successful management strategy would include thinning regimes, increasing light availability at sapling level and reduce browsing damages.

Canopy disturbance will affect other factors important for oak seedling growth such as interspecific competition and browsing (Löf 2000, Kelly 2002, Dillaway et al. 2007, Harmer and Morgan 2007). The short- and long-term effects of such a canopy disturbance on the oak recruitment but also the biodiversity in 25 mixed broadleaved stands are currently being studied using a partial-cutting experiment replicated at landscape level (Götmark 2007). In each of the 25 stands two treatments were applied; partial thinning (removal of 26% of the basal area (mean basal area 29 m^2 ha^{-1})) and no thinning (free development or "hands off"). After 8 years, the partial thinning favours growth and survival in both advanced and naturally oak regeneration (Leonardsson and Götmark 2011).

Increasing the light availability on the forest floor will however not only favour oak seedling growth but also the growth of herbaceous and woody vegetation, which may affect and delay the recruitment of new oak into the overstory (e. g. Lorimer et al. 1994, Löf 2000, Collet et al. 2002, Harmer and Morgan 2007). Preliminary results from Leonardsson and Götmark (2011), suggest that the growth response of shrub species, such as Hazel (*Corylus avellana* L.) and Alder Buckthorn (*Frangula alnus* Mill.) will exceed that of the broadleaved tree species after a partial thinning in oak-rich mixed broadleaved forests. Whereas, competition from herbaceous vegetation is known to stagnate oak seedling growth, shrubs may facilitate or hinder oak seedling growth (Löf 2000, Pagés et al. 2003, Man et al. 2008, Jensen et al. 2012a, b).

High population densities of ungulate browsers in a conifer-dominated landscape results in significant browsing damages, fencing is therefore nearly always required when regenerating oak in Sweden (Swedish Forest Agency 2009), both in production and conservation forest. However, erecting and maintaining a fence are costly for the forest owner, especially for smaller stands – often the case in mixed oak-rich stands of conservation value.

Physical structures such as deadwood barriers and living shrubs have been found to reduce damages by ungulate browsers and grassers to tree saplings (Chantal and Granström 2007, Uytvanck et al. 2008, Pihlgren 2009). This associate resistance may occur as a result of physical traits (thorns, height and density) or through chemical unattractiveness of the surrounding vegetation (Callaway and Walker 1997, Barbosa et al. 2009, Harmer et al. 2010). Jensen et al. (2012a) found that the probability of an oak (*Quercus robur* L.) being browsed was on average 20 percent points lower for individuals growing among shrubs than for individuals growing in the absence of shrubs. When browsing did occur the browsing intensity (measured at loss in height growth) was also lower for oak saplings among shrubs.

We therefore suggest that naturally occurring shrubs may be one tool to regenerate oak forests of conservation interest, especially if browsing restricts oak seedling development and permanent exclusion is too costly. Using hazel for the establishment of oak regeneration in shelterwood systems is a common practice in Luxembourg, for instance. However, utilizing shrubs as protection is complex (Jensen 2011), and stronger competition might prolong the regeneration phase by lowering growth. The recruitment of new oaks in mixed oak-rich forest of conservation interest will therefore involve regular vegetation management especially for the shrubs. Some potential to reduce tending intensity could be achieved by proper light conditions for oak, e. g. by the formation of large gaps (Schütz 1991). Local vegetation management that takes advantage of the position of oak seedlings in relation to canopy and angle of insolation might bear an additional potential (which is currently tested in Germany, RLP 2009). However, without conventional silvicultural regeneration measures (paragraph Establishment under Silviculture in pure oak stands), the period of recruitment may be long (25 - 50 years) and in some cases a continuous process. There is therefore a great need for long-term evaluation of the temporal and spatial interaction affecting the regeneration success in oak-rich forests of conservation value.

Conclusions

Considering the decline of oak proportion and insufficient regeneration, more active promotion seems necessary to maintain the current oak proportion. However, oak conservation needs intensive management. There are conventional silvicultural methods to establish oak stands, which can be applied successfully in mature oak stands or after clear-cuts to a large extent. Due to a considerable proportion of oak trees in mixture with conifers, the promotion of single oak trees by release from competing trees is another, but even more intensive management option. Future growth of single oak trees can be expected to be slow compared to competing spruce trees, and would require frequent silvicultural interventions. Management costs of such measures will not always be covered. If single oak tree promotion can be afforded, vital individuals could be released from competitors (by measures for nature conservation and by normal thinning operations in coniferous stands). The selection potential of vital trees could be increased by utilizing Jay behaviour and considering landscape aspects in forest management planning. However, initial vitality of supressed trees and growth response potential after releases is poorly studied.

Direct measures against browsing (hunting, fencing, single-tree protection) can also increase the number of successfully established oak saplings. Naturally occurring shrubs could provide additional protection (at least during a certain period), if browsing restricts oak seedling development. In stands with conservation interest, locally more suitable light conditions for oak seedlings can be created by management, i. e. by thinnings (Götmark 2010) or gap formation (Schütz 1991) in windfirm forest.

The establishment of even-aged oak stands by shelterwood cutting or after clear-cut is an important option to maintain the current oak proportion. Such conventional methods under traditional forest management regimes seem most promising from a forester´s perspective, with establishment rates required for successful management of oak for timber production. An additional option is single oak tree promotion, especially in nature conservation areas. On the other hand, heavy removals of standing volume after a mast year would regenerate oak stands in reserves as well, if long-term preservation of oak over the next stand generation has highest priority. Depending on the priority to oak, single tree promotion in plantation forests can also be expected to have a positive effect on the oak proportion.

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