Forest Ecology and Management 354 (2015) 1–9

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Exclosures can favour natural regeneration of oak after conservation-oriented thinning in mixed forests in Sweden: A 10-year study

Jenny Leonardsson [a,*], Magnus Löf [b], Frank Götmark [a]

[a] University of Gothenburg, Department of Biological and Environmental Sciences, Box 463, SE 405 30 Göteborg, Sweden
[b] Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre, Box 49, Rörsjöv 1, SE 230 53 Alnarp, Sweden

ARTICLE INFO

Article history:
Received 20 March 2015
Received in revised form 1 July 2015
Accepted 6 July 2015
Available online 11 July 2015

Keywords:
Canopy disturbance
Forest restoration
Succession
Ungulates
Browsing
Quercus spp.

ABSTRACT

Oak trees are biodiversity hotspots in many landscapes and provide habitats for several organism groups, including species that are rare or threatened by extinction. Oak regeneration in the northern hemisphere is often poor, which is a serious problem in many oak-rich conservation forests. Competition from other vegetation and browsing by ungulates are two factors that limit oak regeneration. In 13 mixed oak-rich forests with high values for biodiversity we tested conservation-oriented thinning. Trees and shrubs were harvested for biofuel, but the main aim was to favour oak regeneration and biodiversity. On average, 23% of the initial basal area was removed during the winter 2002/2003. After thinning, we set up exclosures to protect oak seedlings from browsing. In 2012, after ten growing seasons, the exclosures had favoured regeneration of oak by reducing ungulate browsing, though the effect was weak. Tall oak saplings (>130 cm) were present in exclosures at five sites, and no such new stems were recorded in control plots with browsing. These five sites were characterized by higher canopy openness, and probably higher light availability, compared to the other sites. Other broadleaves, and especially shrubs, increased much more in density and height than oaks, in both exclosures and control plots. Thus, conservation-oriented thinning in combination with fences to protect oak seedlings from browsing ungulates, increased oak regeneration in the mixed conservation forests, but control of competing understory vegetation in exclosures is probably also needed.

1. Introduction

Oak trees (*Quercus* spp.) are important components of many temperate forests, providing habitats for several organism groups (Johnson et al., 2009; Lindbladh and Foster, 2010; Tyler, 2008), such as beetles (Ranius and Jansson, 2000), lichens (Thor et al., 2010), fungi (Ranius et al., 2008), pseudoscorpions (Ranius and Wilander, 2000), bats (Ruczynski and Bogdanowicz, 2008) and birds (Pasinelli, 2000), and many rare and red-listed species (ArtDatabanken, 2015). Oaks can grow large on open habitats such as agricultural fields and woodland pastures (Hartel et al., 2013; Paltto et al., 2011; Rogers and Russell, 2014). Land-use changes during the last century, such as the abandonment of woodland pastures and other agricultural lands (e.g. Bergmeier et al., 2010) and fire-suppression (Rogers and Russell, 2014), have led to recruitment and regrowth of other woody species and closed canopy forests (e.g. Brudvig and Asbjornsen, 2007; Paltto et al., 2011). This may result in reduced growth of oak seedlings due to insufficient light and competition from other more shade-tolerant trees and shrubs (Lorimer et al., 1994).

Oak regeneration is generally considered poor in many mixed forests, and may be insufficient to sustain oaks in these ecosystems (Bobiec et al., 2011a; Brudvig, 2008). In mixed forests with closed canopies and shade-tolerant trees, oak regeneration seems to require disturbances (Bobiec et al., 2011b). Natural disturbances, such as windthrow, can create canopy gaps in mixed forests by breaking stems and uprooting trees (Peterken, 1996). However, if natural disturbances are rare, active management may be needed to favour oak regeneration. Gap-creation will increase the light availability in the understory, which may favour oak regeneration through higher seedling establishment and growth, and increased growth of advance regeneration (Brudvig and Asbjornsen, 2009; Johnson et al., 2009). Oak regeneration can also be induced by other disturbances that reduce competition from other vegetation,

* Corresponding author.
E-mail address: jenny.leonardsson@gu.se (J. Leonardsson).

http://dx.doi.org/10.1016/j.foreco.2015.07.004
0378-1127/© 2015 Published by Elsevier B.V.

such as understory removal (Lorimer et al., 1994), surface fire (van Lear and Watt, 1993) and diseases (Brunet et al., 2014).

Currently, large ungulate browsers negatively affect oak recruitment in many areas (e.g. Mihók et al., 2009; Smit et al., 2012; Thomas-Van Gundy et al., 2014). Through their browsing preferences ungulates can reduce the abundance of some species, hence changing species composition of trees and other plants (Pellerin et al., 2010; Perea et al., 2014; Rooney and Waller, 2003). In mixed forests, deciduous trees are often browsed to a higher extent than coniferous ones, and oaks seem to be preferred (Bergquist et al., 2009; Götmark et al., 2005; Kullberg and Bergström, 2001). The browsing pressure seems to be low on small oak seedlings (<50 cm tall; Götmark et al., 2005), but as seedling height increases so does also browsing intensity (Jensen et al., 2012; Kullberg and Bergström, 2001; Smit et al., 2012), probably because taller saplings are at a more comfortable browsing height for the ungulates (Pellerin et al., 2010). High browsing intensity can lead to prolonged regeneration time (Bergquist et al., 2009; Gill and Beardall, 2001; Götmark et al., 2005) and repeated browsing can reduce the survival of oak saplings (Kelly, 2002). Fencing to exclude ungulates increases the growth and survival of oak seedlings, but few such longer-term studies exist, especially in conservation forests (Abrams and Johnson, 2012; Kelly, 2002; Pigott, 1983).

In the Swedish Oak Project, oak-rich mixed forests with high values for biodiversity have been studied since 2000 (e.g. Götmark, 2013, 2009, 2007; Nordén et al., 2012, 2008). At each of 25 forests we have one plots (1 ha) treated with conservation-oriented thinning (hereafter thinned plot). The aims of the project are to favour oaks (*Quercus robur* L. and *Quercus petraea* (Mattuschka) Liebl.) and to promote conservation values and biodiversity. In addition, the project is testing sustainable harvest of biofuel. In a 3-year study of all 25 forests the survival and growth rate of oak seedlings increased after thinning, with canopy openness as the strongest explanatory factor, and seedling size was positively related to survival (Götmark, 2007).

Most studies about protective structures for oak regeneration, such as shrubs, have been done in open woodlands (e. g. Bakker et al., 2004) or in areas with high abiotic stress, such as drought (Gómez-Aparicio et al., 2008; Perea and Gil, 2014). But a short-term study in 10 of our 25 forests evaluated the effect of shrubs and exclosures on planted oak seedlings; fencing provided the best protection against browsing (Jensen et al., 2012). Shrubs reduced the frequency and intensity of browsing in unfenced plots, until the oak seedlings overtopped the shrubs. After two and a half years, the mortality of oak seedlings increased outside fences, also in the presence of shrubs. The authors concluded that shrubs may initially facilitate regeneration of oak, however, they point out that long-term studies are needed.

Here we used data from 13 of our forest sites to analyse ungulate browsing and oak regeneration over 10 years. In the thinned plots, we used previously investigated small sub-plots with many oak seedlings where fences against ungulates were established, and we used other small sub-plots as unfenced controls. We tested the following two alternative hypotheses:

Hypothesis 1. Exclosures favour natural oak regeneration in mixed oak-rich forests following conservation-oriented thinning. Our prediction was that natural regeneration of oak is improved by exclusion of ungulate browsers, compared to controls with no restriction of browsing at the same study sites. Since browsing pressure was low on small oaks (Götmark et al., 2005) we expected that the density of oak seedlings (<20 cm tall) would be relatively similar in controls and exclosures. In contrast, increased seedling height led to increased browsing intensity (Jensen et al., 2012), hence we predicted that the density of short saplings (20–130 cm) and tall saplings (>130 cm <10 years) should be higher in exclosures compared to controls.

Hypothesis 2. Exclosures favour other browsing sensitive woody species more than oak. Several shade-intolerant fast-growing shrubs and trees are often also heavily browsed, for instance aspen and rowan (Edenius and Ericsson, 2015; Myking et al., 2013, 2011). If they are protected from browsing, they may reduce the oak regeneration through competition (Beckage et al., 2008). We tested if densities of other woody species are related to the densities of oak saplings. In addition, we compared height growth of the woody species within and outside exclosures.

We also analyzed oak regeneration in relation to forest composition and environmental factors, namely initial basal area of oaks, broadleaves and conifers, canopy openness, precipitation and soil characteristics. Our present study of oak regeneration contributes with 10 years experimental knowledge about fencing for oak regeneration, especially useful for management of mixed forests where conservation is the main aim.

2. Materials and methods

2.1. Characteristics of the study sites

The forests of southern Sweden are dominated by production stands of the conifers *Picea abies* (L.) Karst and *Pinus sylvestris* L. (Swedish Statistical Yearbook of Forestry, 2014), but broadleaved species are locally common (mainly *Betula* spp. but also *Quercus* spp. and others). We studied 13 oak-rich mixed forests (Fig. 1 and Table 1) in the southern part of Sweden (12–17°E and 56–58°N, between 5 and 230 m above sea level). The studied forests were previously semi-open, with small fields or pastures, abandoned 50–80 years ago. Secondary succession produced closed canopy mixed forests. Large oaks (about 80–200 years old) occur at the sites, which are set aside for biodiversity, either as nature reserves (4) or woodland key habitats (9). Nature reserves have a stronger protection status than woodland key habitats (e.g. Timonen et al., 2010). The soil at the sites is mainly mesic moraine (till), on relatively level ground with slightly stony surface. The mean monthly precipitation (July) from 2003 to 2012 was highest (109 mm) at the western sites and lowest (93 mm) at the eastern coastal sites, and within-season variation is generally low (Swedish Meteorological and Hydrological Institute, www.smhi.se). The daily average temperature in July between 2003 and 2012 was 17.2 °C at the westernmost sites and 17.8 °C at the eastern sites (www.smhi.se).

We conducted the present study in the thinned plots at our 13 sites. Before thinning the mean basal area per hectare at breast height (130 cm) was 22.5 m^2 (range 16.0–26.9, $n = 13$). On average 23.2% (range 9.3–33%, $n = 13$) of the basal area was cut and harvested for biofuel, but tops and branches of larger trees were left in the plots in accordance with the Swedish regulations. Understory trees (0.5–4.9 cm in diameter at 130 cm) were not measured and hence not included in basal area; about 50–90% of them were cut and harvested for biofuel.

The proportion of oaks (*Quercus* spp.) in the plots in 2002, before thinning, was on average 46% of the basal area (range 12–77%, $n = 13$). This proportion increased after thinning (no data available), since more of the non-oak tree species were cut. Other species varied considerably among sites, but before thinning Norway spruce (*P. abies* (L.) Karst.) was on average the second most common tree (in mean basal area) followed by birch (*Betula pubescens* Ehrh. and *Betula pendula* Roth), aspen (*Populus tremula* L.), ash