Forest Ecology and Management 349 (2015) 94–105

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Effects of different harvesting intensities on the macro nutrient pools in aged oak coppice forests

Patrick L. Pyttel *, Merle Köhn, Jürgen Bauhus

University of Freiburg, Chair of Silviculture, Tennenbacherstr. 4, D-79085 Freiburg, Germany

ARTICLE INFO

Article history:
Received 7 January 2015
Received in revised form 7 March 2015
Accepted 22 March 2015
Available online 24 April 2015

Keywords:
Aged coppice
Oak
Hornbeam
Nutrient content
Nutrient export
Harvesting intensity

ABSTRACT

Improved knowledge concerning nutrient removals through harvesting in former coppice forests is crucial for the sustainable management of these forests. This is especially true if the resumption of coppicing is being considered to serve increasing fuel wood demands. In this study the nutrient contents of various tree compartments of sessile oak (*Quercus petraea* (Mattuschka) Liebl.) and hornbeam (*Carpinus betulus* L.) from two sites differing in soil fertility were determined using allometric equations to calculate nutrient removal associated with different harvesting intensities.

Stand level nutrient contents in tree compartments were comparable between both study sites. The results for exchangeable base cations, plant available P, and total N indicate that coppicing is not a priori an unsustainable forest management system. On sites with large soil nutrient pools, even whole trees may be harvested without substantial reductions in ecosystem nutrient pools. However, on sites with a low nutrient capital, current harvesting practices would result in relatively high rates of nutrient export. In these stands, harvesting intensity should be based on careful selection of the tree compartments removed, e.g. stem only, to conserve nutrients on site.

This study describes the impact of simulated tree harvesting on soil nutrient pools in aged coppice forest for the first time. Based on our findings, general assumptions related to soil sustainability of coppicing are replaced by clear recommendations regarding silvicultural nutrient management. Considering the large areas of aged coppice forests in Europe this study provides a methodological template which is needed to enhance their sustainable management.

1. Introduction

Coppicing is the earliest form of regular forest management (Buckley, 1992). Only one century ago, coppice forests ensured the economic prosperity of large regions in Central Europe. Today this type of forest management is rather uncommon. From the beginning of the 20th century onwards, coppice forests were abandoned or converted into high forest. The latter process was either gradual, i.e. stands were managed like high forests without changing species composition, or an abrupt transformation, in many instances to conifer monocultures, through planting on clear cut sites after the stumps were removed or killed with herbicides (Papaioannou, 1938). Where coppice forests were not converted or transformed into high forests or harvested within a 45 year rotation, they have grown old and are now described as former or aged coppice forests.

Today managed coppiced forests (i.e. younger than 45 years) cover only less than 1% of Germany total forest area (Kaltschmitt et al., 2009). The area of abandoned, older coppice forests is assumed to amount to several thousand km^2 and is thus substantially higher than the area of conventional coppice forests. However, since most privately owned forests are not inventoried, the actual area is not certain. Most aged coppice forests occupy an intermediate stand development phase between regularly cut coppice and high forest. However, their species composition and the frequency of distinctive structural elements (i.e. high stem density, small stem and crown dimensions, large and multi-stemmed stools) is still largely similar to that of managed coppice forests.

A resumption of coppicing in these aged coppice forests may be triggered by increasing fuel wood demands (Suchomel et al., 2012). So far, however, the resumption of coppicing has proceeded slowly for various reasons including the perceived environmental damage through clear felling and the removal of almost all woody biomass.

---

* Corresponding author. Tel.: +49 (0)761 203 3679; fax: +49 (0)761 203 3781.
E-mail addresses: patrick.pyttel@waldbau.uni-freiburg.de (P.L. Pyttel), merlekoehn@gmx.de (M. Köhn), juergen.bauhus@waldbau.uni-freiburg.de (J. Bauhus).

http://dx.doi.org/10.1016/j.foreco.2015.03.037
0378-1127/© 2015 Elsevier B.V. All rights reserved.

In fact there has been a long-standing controversy surrounding the impact of coppice management on soil (see e.g. Neubrand, 1869), but only very few contributions to this debate are based on actual measurements.

Investigations in managed 20 year old birch and oak coppice forests growing on acid soils found that coppicing did not reduce soil nutrient availability despite short rotation periods and the relatively small soil nutrient pools of coppice woods compared to high forest (Hölscher et al., 2001). Apparently the traditional management practices with frequent soil disturbances resulting from cutting and burning accelerated nutrient turnover and resulted in higher availability of the nutrients Ca, K, Mg and N.

In contrast, the depletion of soil nutrients caused by timber extraction in coppice systems was reported to be always higher relative to high forests (Ranger and Nys, 1996, see also references herein). Harvesting of coppice stands occurred traditionally at early stand development stages and more or less whole trees were harvested including compartments such as twigs and branches with high nutrient concentrations. Thus a certain proportion of biomass removed from coppice forests contains more nutrients than the equivalent biomass from high forests, which comprises mostly large diameter stem wood, which is low in nutrient concentrations. Further nutrient losses may occur through leaching with seepage water during or shortly after harvesting (Spangenberg et al., 1996).

However, scientifically reliable results for the consequences of coppice forestry on ecosystem nutrient pools are still rare (Hölscher et al., 2001). Thus if the resumption of coppicing in aged coppice forests is expected to serve an increasing fuel wood demand, detailed studies on the effects of harvesting on ecosystem nutrient stocks are urgently needed because most of these forests grow on sites with steep slopes, potentially high water runoff and poor soil nutrient status (Ellenberg and Leuschner, 2010).

In this study, we simulate the impact of tree harvesting on ecosystem nutrient pools in aged coppice forest for the first time. We investigated the macronutrient concentrations (N, P, K, Ca, Mg, S) in various above-ground tree compartments and related total above-ground nutrient stocks to nutrient pools in the soil of two aged oak coppice stands differing in nutrient availability. The main objectives of this paper were: (i) to obtain detailed information on the nutrient distribution within sessile oak (*Quercus petraea* (Mattuschka) Liebl.) and hornbeam (*Carpinus betulus* L.); (ii) to quantify nutrient removals under different, simulated harvesting intensities; and (iii) to derive practical silvicultural recommendations to ensure that soil fertility can be sustained on sites where the resumption of coppicing is being considered.

2. Material and methods

2.1. Experimental sites

The State of Rhineland-Palatinate (south-west Germany) has the largest area of abandoned coppice forests among the German states. It is assumed that about 160,000 ha of forest, equivalent to almost 20% of the state's total forest area is of coppice origin (Helfrich and Konold, 2010).

In Rhineland-Palatinate we selected the study sites "Weisel" (hereafter called W) and "Baumholder" (hereafter called B) for the establishment of harvesting experiments. Selection criteria were stand age (both stands were representative of the dominant age class of the states aged coppice forests) and soil type (stands differed in terms of parental rock and nutrient supply to examine the influence of biomass removal on ecosystems with contrasting nutrient stocks). Both stands were dominated by *Q. petraea* with *C. betulus* in a secondary canopy stratum.

Study site W (1.44 ha in size) is situated on a south-south-easterly facing slope at 380 m above sea level and close to the municipalities of Weisel and Sauerthal (Lat. 50.075366 Long. 7.792135). Common soil types in this area are luvisols and brown earths of moderate base supply developed from argillaceous schist. Mean annual temperature is 8.3 °C and mean annual rainfall is 760 mm (Gauer, 2005).

Study site B (0.96 ha in size), ca. 10 km east of the town of Baumholder (Lat. 49.62289, Long. 7.439991) is characterized by loamy, nutrient rich cambisol soils developed from melaphyre. Annual average temperature is 6.9 °C (1971–2000 period) and average annual precipitation is 850 mm. The study site is located at ca. 380 m above sea level on a south-west facing slope.

The last coppice cuts of both stands occurred about 85 years ago. Since then there have been no silvicultural treatments. However, it is not known when the coppicing practice at these sites started initially. Studies of prehistoric charcoal piles suggest that coppicing may have begun around 800 B.C. (Landesforstverwaltung Rheinland-Pfalz, 1987). Since coppicing in historical times was associated with temporary intense agricultural use (as mentioned above) a significant alteration of the soil nutrient regime can be assumed (sensu Glatzel, 1991).

2.2. Experimental design

2.2.1. Sample tree selection

During winter 2008/09, all trees of all species with a dbh $\geqslant$ 7 cm were inventoried (total $N = 3488$ trees) and permanently tagged for subsequent measurements. The inventory procedures included species identification and measurement of dbh. Subsequently, the diameter range of all oak (8.9–29.7 cm) and hornbeam (7.0–19.2 cm) trees at each study site was divided into 12 diameter size classes (class size 2 cm for oak and 1 cm for hornbeam). From every size class one representative tree was selected and destructively sampled for nutrient analysis. Thus sample tree selection criteria were the dbh and the tree shape avoiding ill-formed individuals with strong forks or other peculiarities (*sensu* André and Ponette, 2003). In total, 48 trees were sampled; 12 trees per species and per site.

2.2.2. Biomass determination and sample extraction

Sampling was carried out in winter (2008/2009) to avoid any impact of the growing season leading to changes in element concentrations due to translocation of nutrients from storing tissues to new or younger plant parts (Ponette et al., 2001).

To record the total above ground biomass, all 48 sample trees were felled as close to the ground as possible. After felling, tree height and green crown height (defined by the height of the first living primary branch at the stem junction) were measured to the nearest cm. Thereafter sample trees were divided into the compartments "stem" (biomass from stem base to the first living primary branch or until a maximum top diameter of 7 cm over bark), "branch wood" (branch sections $\geqslant$ 7 cm), "small wood" (branch sections < 7 cm and $\geqslant$ 4 cm) and "twigs" (branch sections < 4 cm). All threshold diameters for compartment separation were measured over bark. Tree compartment abbreviations, used throughout this study are summarized and described in Table 1.

Fresh weight of all tree compartments was measured directly in the field with portable spring scales. Sub-samples were taken from all compartments to determine moisture content and wood density as follows: (a) four twig samples were taken randomly from the appropriate compartment, (b) two sections of small wood (each about 6 cm long) were taken from the lower and upper end of one branch in the crown centre; (c) two branch wood section samples of ca. 6 cm length were taken from branch wood