Forest Ecology and Management 270 (2012) 291–301

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

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

# Spatially explicit determination of individual tree target diameters in beech

Henrik Meilby *, Thomas Nord-Larsen

*University of Copenhagen, Forest and Landscape, 23 Rolighedsvej, DK-1958 Frederiksberg C, Denmark*

ARTICLE INFO

*Article history:*
Received 6 May 2011
Received in revised form 9 August 2011
Accepted 20 August 2011
Available online 21 October 2011

*Keywords:*
Optimization
Simulated annealing
Expectation value
Log quality
*Fagus sylvatica* L.

ABSTRACT

In its basic definition, the individual tree target diameter is the hypothetical end diameter to which trees should be grown in order to maximize the expectation value of the forest stand. Most studies on target diameter harvesting have focused on the estimation of simple, static target diameters common to all trees or groups of trees. However, dynamic interaction between trees and differences in growth potential and quality affect the rate of return of individual tree growth, and thereby the target diameter of the tree. Based on a 4.9 ha experimental beech (*Fagus sylvatica* L.) stand in southern Sweden, we estimated individual tree target diameters by maximizing the expectation value of the stand while taking the spatial position and interaction of the trees into consideration. At moderate levels of required rate of return (2–3%) the average target diameter was 59–66 cm with a standard deviation of 13–19 cm. Results indicated that the target diameter depends strongly on stem quality, distance to neighboring trees (competition), and the quality of neighboring trees. When analyzing the effect of including neighborhoods of different size in the assessment of target diameters, the marginal change of the total expectation value remained significant, even when 10–12 trees had already been included, but converged fast for larger neighborhoods. Expectation values obtained using simplified management approaches were 10–20% lower than that of the spatially optimal solution. It is thus evident that the inclusion of the spatial position and quality of individual trees improves profitability of forest management considerably.



## 1. Introduction

The introduction of nature-based or near-natural forestry in central and northern Europe has to a large extent been associated with target diameter harvesting and other selection-type forest management regimes (Richter and Engineer, 1992; Henning, 1996; Kenk and Guehne, 2001). Several authors have argued that selection forestry forms the basis of more sustainable forestry practices that protect ecological structures and functions of the forest, as well as satisfies economic needs of the owner (von der Goltz, 1991; Larsen, 1995; Tarp et al., 2000, 2005). Further, it has been argued that, to some degree, target diameter harvesting mimics the natural dynamics of beech forests in northern Europe (Christensen and Emborg, 1996; Emborg et al., 2000). Based on this notion, such stand management is presumed to protect authentic biodiversity and contribute to a higher degree of resistance and resilience towards disturbances such as windthrow and pests.

In a number of studies, target diameter harvesting has been shown to produce an economically viable alternative to continued even-aged management and clear-felling. For example, in a study of target diameter harvesting in beech in northern Germany, expectation value exceeded that of more traditional cyclic and clear-felling regimes at a required real rate of return of 2–3% (Nord-Larsen et al., 2003). Further, target diameter harvesting resulted in a more attractive cash flow and an increased accumulation of capital in the forest. Similarly, Knoke and Plusczyk (2001) found that the expectation value of transforming even-aged Norway spruce stands to uneven-aged stands exceeded that of continued even-aged management because income from the transformation occurred earlier and more uniformly. The apparent attractiveness of target diameter harvesting is primarily achieved through an increased production of valuable wood at low costs and, in part, this is a consequence of determining maturity for the individual tree rather than for the entire stand (Knoke, 1997; Heding, 2000; Hanewinkel, 2001; Nord-Larsen et al., 2003). To that end, some authors have argued that target diameter harvesting is more flexible in the presence of volatile stumpage prices and hence that the expectation value of transformation to nature-based management is subject to less disturbances compared with other harvest regimes (Knoke, 2001; Knoke and Plusczyk, 2001).

In principle, determination of the optimal rotation age for the individual tree relies on an economic consideration of the marginal revenue of leaving the tree to grow. Since the value of the tree depends heavily on its size, it is convenient to express optimal rotation by the diameter of the tree rather than its age. The tree has reached its target diameter when the required rate of return exceeds the marginal value added by leaving the tree to grow. Thus,

* Corresponding author. Tel.: +45 35331740.
*E-mail address:* heme@life.ku.dk (H. Meilby).

0378-1127/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2011.08.037

the target diameter of the individual tree depends on the required real rate of return and the annual increment (Moog and Karberg, 1992). Further, for trees with high-quality logs an increasing premium is paid with increasing diameter of the stem, whereas such a premium is generally not paid for poor quality logs. Consequently, for a high quality tree the value added through growth is generally larger than for a poor quality tree. Hence, the target diameter tends to increase with increasing quality of the stem (Holm, 1974; Moog and Karberg, 1992).

Most studies emphasizing determination of individual target diameters have ignored the fact that the decision to leave the tree to grow or not, influences the economic return of surrounding trees. In general, leaving a tree to grow will incur a reduction in growth of surrounding trees due to competition and, hence, an opportunity cost. This opportunity cost must be outweighed by the value added by the growth of the subject tree, which in turn leads to a reduction of its target diameter. However, leaving the tree to grow may also have a positive effect on wood quality of the neighboring trees, thereby potentially increasing the target diameter. A related effect is the suppression of regeneration incurred by leaving the tree to grow, which reduces the value of the growing space that the tree occupies. Again, the loss must be outweighed by the value added to the subject tree when leaving it to grow, thereby reducing the target diameter.

From the above it is evident that the target diameter depends on the spatial arrangement of the trees (Hagner et al., 2001; Härtl et al., 2010). This has been ignored in most of the work dedicated to the estimation of target diameters. Therefore, this study aims to (1) demonstrate how the target diameter of individual trees may be estimated while including the spatial arrangement of the trees, (2) assess the size and variation in target diameters thus obtained, (3) evaluate the effect of tree characteristics and their spatial arrangement on individual tree target diameters, and (4) compare results with other and more simplistic stand management scenarios. Analyzes were based on spatially explicit optimization of individual tree target diameters in an experimental stand of European beech in southern Sweden.

## 2. Materials

The experimental stand of European beech in compartment 35c on Trolleholm Estate in Skåne, Southern Sweden, was mapped in autumn 1991 (Jensen and Meilby, 1992). The area of the stand is 4.9 ha and based on annual rings counted on 82 trees felled in December 1991, mean age was estimated at 106 years (std. dev. = 8 years). The stand was established by natural regeneration and is assumed to have been partially incomplete, in part because the shelterwood phase was abruptly terminated by windthrow in December 1902. Hence, grassy glades surrounded by deep-crowned trees still existed in 1991. In some parts of the stand natural regeneration spontaneously started to form during the 1970s and 1980s.

The soil is a clayey loam that easily becomes waterlogged during the early spring. The site quality increases conspicuously from west towards east (Fig. 1) and, as a consequence of this and the heterogeneous stand structure, the stem number is still considerably greater in the western part of the stand than in the eastern. Moreover, the number of trees with short boles of low quality is markedly greater to the west than elsewhere (Fig. 1). The stand was remeasured in 1993, 1995, 2000 and 2007. Stand factors as of 1993 are included in Fig. 1. Assessment of the commercial bole

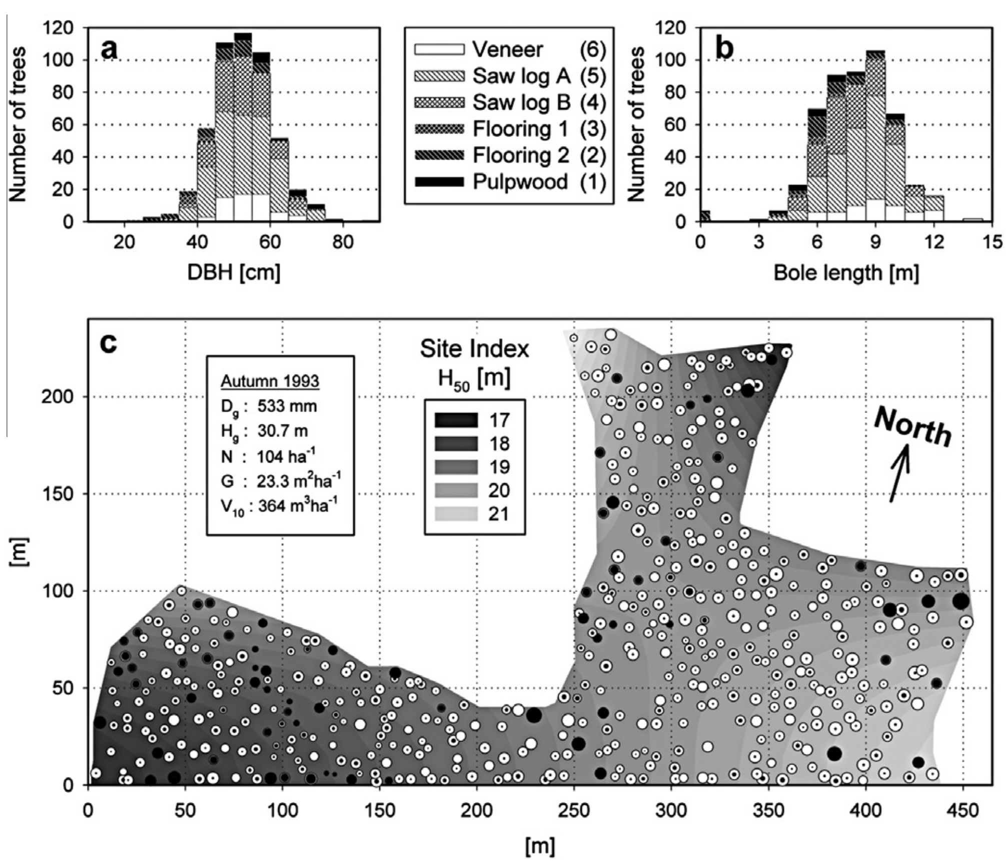


**Fig. 1.** Stand map and characteristics of the experimental stand (compartment 35c). (a) Diameter and bole quality distribution; (b) Bole length and quality distribution; c. Stand map. Diameter of the circular symbols is proportional to breast height diameter (*dbh*). Relative size of black dots inside circles indicates stem quality: No black dot corresponds to veneer quality; totally filled circle to pulpwood quality. Estimated site index is indicated by background shading (see color scale).