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Suitability of the selected statistical distributions for fitting diameter data in distinguished development stages and phases of near-natural mixed forests in the Świętokrzyski National Park (Poland)

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Abstract

The purpose of this study is to evaluate goodness of fit of empirical and theoretical DBH distributions in near-natural forests with fir (*Abies alba* Mill.) and beech (*Fagus sylvatica* L.) representing different development stages and phases.

The goodness of fit was tested using the χ^2 test and the error index (e) of Reynolds et al. [Reynolds, M.R., Burk, T., Huang, W.-H., 1988. Goodness-of-fit tests and model selection procedures for diameter distribution models. For. Sci. 34, 373–399].

The Weibull and gamma distributions approximated the actual DBH distributions in 14 and 8 stands, respectively (out of 17 analysed). The results suggest a relationship between the stage and phase of stand development and the type of distribution. The normal distribution most closely approximated the actual DBH distributions for stands in the growing up/break-up stage, one-storied structure phase [younger generations I and II]. The stands in the break-up stage, two-storied structure phase [upper story—younger generation II] were characterised by the DBH distribution close to gamma distribution. The exponential, gamma, and Weibull distributions were best for stands in the growing up stage, selection structure phase [upper layer—younger generation II].

Keywords: DBH distribution; *Abies alba*; *Fagus sylvatica*; Goodness-of-fit test; Error index (e); Świętokrzyski National Park

1. Introduction

The estimation of goodness of fit of empirical and theoretical DBH distributions in near-natural, natural, and primeval forests of different developmental stages and phases is of great importance for nature conservation, as well as for theoretical and practical forestry (e.g., von Oheimb et al., 2005; Rouvinen and Kuuluvainen, 2005). The use of DBH distributions includes modelling developmental cycles of the forest and constructing stand structure models, which is especially important for planning protection treatments in the partial protection zones of national parks and for maintaining permanent and balanced development in commercial forests (Shiver, 1988; Borders and Patterson, 1990; Goelz and Leduc, 2002). Knowledge of diameter distribution and other characteristics of stands in definite stages and phases of development is also necessary during the transformation of zones partially or closely protected, as well as during sylvicultural treatments aiming at the creation of vital stands with structure and composition close to those of primeval forests (e.g., von Oheimb et al., 2005; Rouvinen and Kuuluvainen, 2005).

In pure fir forests and fir–beech forests, with fir or beech predominance, of Central Europe, the DBH distribution falls between a one-sided exponential distribution and a symmetrical normal distribution (Koop and Hilgen, 1987; Pontailler et al., 1997; Jaworski et al., 1999, 2000; Emborg et al., 2000; Maltamo et al., 2000). In Central Europe, no studies concerning the approximation of actual diameter distributions with theoretical distributions have been carried out in near-natural mixed forests with fir and beech representing various stages and phases of development.

In the Świętokrzyskie Mountains, there are fragments of forests that have seen little exploitation in the past (Krysztofik, 1976) due to difficulties associated with quick and cheap timber hauling (Gądek, 2000). During the 1950s, the largely protected Świętokrzyski National Park was created. The oldest strictly protected forest reserves were created earlier, in 1921

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(Chełmowa Góra) and 1922 (Święta Katarzyna and Święty Krzyż). In the 1920s, 1940s, 1970s, and 1980s, the phenomenon of fir decline was observed in the Świętokrzyski National Park (Gądek, 1993). This disrupted the forest development cycle, which resulted in the formation of development stages and phases observed during the activity of factors causing middle-scale disturbances (between the death of a single tree and a catastrophic break-up of stands) (Podlaski, 2004). They were caused by abiotic as well as biotic factors (very cold and long winter 1928/1929, followed by the outbreak of fir tortricids and bark beetles) (Sierpiński, 1977; Podlaski, 2002).

The purpose of this study is to evaluate goodness of fit of empirical and theoretical DBH distributions in near-natural fir (*Abies alba* Mill.)–beech (*Fagus sylvatica* L.) forests in different stages and phases of development, in the Świętokrzyski National Park (Poland).

2. Study area

The investigations were carried out in the Święta Katarzyna, Święty Krzyż, and Góra Chełmowa forest sections of the Świętokrzyski National Park situated in the Świętokrzyskie Mountains (geographical coordinates: 50°50′–50°58′N, 20°48′–21°08′E). Together, these forest sections occupy an area of over 2348 ha, i.e., about 31.5% of the present (2004) total area of the park. Naturally regenerated near-natural forests chosen for this study are composed of native tree species and that have been managed sparingly in the past.

The Distric Cambisol and Haplic Luvisol soils predominated in the investigated area (Kowalkowski, 2000). The types and sub-types are given according to FAO, ISRIC, and ISSS (1998). Under these conditions, the following plant associations have developed: *Dentario glandulosae-Fagetum*, *Abietetum polonicum*, and *Querco roboris-Pinetum*. Their names are in accordance with Matuszkiewicz (2002).

The data obtained during a long-term observation period (1955–1994) at the Święty Krzyż meteorological station (575 m above the sea level) showed that the mean annual temperature was 5.9 °C (the mean temperature in January was −5.2 °C; in July it was 15.9 °C), the mean annual precipitation was 923 mm, and the growing season lasted for about 182 days.

3. Methods

3.1. Field measurements

In the Święta Katarzyna, Święty Krzyż, and Chełmowa Góra forest sections, 17 experimental plots, 0.1–0.3 ha in size, were selected at random. All sampled experimental plots were marked on forest management maps with a scale of 1:5000 and traced out in the field by compass measurements. A detailed description of this selection procedure may be found in the paper of Podlaski (2005).

In each experimental plot, the stage and phase of the stand were determined (Podlaski, 2004). The main criteria used to determine stages and phases in forest development during this study were the following (Korpel', 1982, 1995):

(1) tree age distribution;
(2) vertical stand structure;
(3) tendency in volume increment (increasing or decreasing).

When estimating the tree age the following generations were distinguished:

(1) OG—older generation, formed by firs above 150 years of age, and beeches above 100 years of age;
(2) YGI—younger generation I, composed of firs from about 50 to about 150 years of age, and beeches from about 20 to about 100 years of age;
(3) YGII—younger generation II, formed by firs below 50 years of age, and beeches below 20 years of age.

The DBH of all trees greater than 6.9 cm in diameter was measured. Height measurements included the number of trees needed to plot the height curve for each tree species.

3.2. Data analysis

The actual heights of trees were smoothed using the Näslund function (1936), while volume was determined using tables constructed by Czuraj (1991). Stand volume was calculated as the sum of volumes of individual trees in each diameter class.

Goodness of fit of empirical DBH distributions was tested with six theoretical distributions: normal, logarithmic-normal, Weibull, gamma, logistic, and exponential. The selected theoretical distributions:

(1) were most often used by different authors to approximate actual DBH distributions (e.g., Rennolls et al., 1985; Maltamo et al., 1995, 2000; Liu et al., 2002);
(2) most exactly approximated actual DBH distributions in mixed forests of various structure (e.g., Zasada, 1995; Rymer-Dudzińska and Dudzińska, 1999, 2001; Liu et al., 2002);
(3) their parameters are relatively easy to calculate (Zarnoch and Dell, 1985; Borders et al., 1987; Borders and Patterson, 1990; Kamziah et al., 1999).

The parameters of distributions were calculated using Statgraphics Plus ver. 5.1 (MANUGISTICS, 2001). The location parameter ε was assumed to be 6.9 (Zhang et al., 2003).

To estimate goodness of fit of actual DBH distributions with theoretical distributions, the test χ^2 (Reynolds et al., 1988) and the error index (e) proposed by Reynolds et al. (1988) were used.

$$e = N\sum_{j=1}^{k}\left|\int_{I_j} w(x)\,\mathrm{d}\hat{F}(x) - \int_{I_j} w(x)\,\mathrm{d}F^*(x)\right| \quad (1)$$

where x is DBH (cm), $\hat{F}(x)$ the theoretical CDF of diameters on the plot predicted by the model, $F^*(x)$ the empirical CDF of