

Parameter Estimation of Weibull Growth Models in Forestry

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Abstract—The main aim of this paper is to discuss some certain properties of three Weibull growth models in forestry viewpoint. The parameters of these models are estimated using Newton-Raphson iteration method for the mean diameter at breast height data and top height growth data originated from the Bowmont Norway spruce thinning experiment, sample plot 3661. The average height of 12 sweeping Higan Cherry trees planted in Washington, D.C. is also used. The initial value specifications of the parameters for use of any iterative methods of estimation are also provided.

Key words— Initial value, Parameter estimation, Weibull model, Newton-Raphson method, Growth model, derivative, Mathematical Properties.

I. Introduction

The Weibull model was first introduced by Ernst Hjalmar Waloddi Weibull in 1951. Initially it was described as a statistical distribution. It has many applications in population growth, agricultural growth, height growth and is also used to describe survival in cases of injury or disease or in population dynamic studies [7]. In 1997, Lianjun Zhang [13] used this model to describe tree height-diameter data of ten conifer species. In the paper by Fekedulegn et al. [6] used this model for the top height data of Norway spruce from the Bowmont Norway spruce Thinning Experiment. Colbert et al. [1] have tried to define some character developments such as forest trees height growth and diameter development by using the model. The paper by Karadavut et al. [8] used the model to evaluate the relative growth rate of silage corn. Ozel and ertekin in 2011 [10] studied the Weibull growth model and applied it to the oriental beach Juvemilities growth. Weibull model is also used to study the height growth of Pinus radiata by Colff and Kimberley in 2013 [2]. Lumbres et al. [9] used this model to describe the diameter at breast height of Pinus Kesiya. The Weibull growth model can be derived from the one parameter Weibull distribution function, which is given by

$$F(x) = 1 - \exp(-x^\delta) ; x \geq 0, \quad (1)$$

where $\delta > 0$ is a shape parameter. The distribution function has the point of inflection at $x = [(\delta - 1) / \delta]^{1/\delta}$ and $F = 1 - \exp\{-(1 - \delta^{-1})\}$. Then the eq. (2) can be used to get a sigmoidal growth curve for empirical use [12].

$$f(x) = \beta + (a - \beta)F(kx; \theta) \quad (2)$$

For the Weibull distribution,

$$f(x) = a - (a - \beta)\exp\{-(kx)^\theta\}. \quad (3)$$

The form of the model (3) is the model that David Ratkowsky [11] calls the Weibull model. The equation (3) can also be written as,

$$w(t) = a - b \exp(-ct^m). \quad (4)$$

Where $a = a$, $b = a - \beta$, $c = k^\theta$ and $m = \delta$. For this study, the model (4) will be considered as the Weibull model with four parameters. Philippe Grosjean [7] used a three parameter Weibull model with considering $\beta = 0$ in eq. (3), which is given in eq. (5). This eq. gives the Weibull model with three parameters.

$$w(t) = a(1 - \exp(-ct^m)) \quad (5)$$

In 2000, Alistair Duncan Macgregor Dove [3] used a two parameters Weibull model to investigate parasite richness of nine species of fishes. He used

$$w(t) = a(1 - \exp(-ct)). \quad (6)$$

This model can be derived from the Weibull model with three parameters by considering $m = 1$ to the eq. (5). Dove also defines the parameters of the model (6) for parasite richness of fishes as a is the maximum regional fauna richness and c is an index of the mean infracommunity richness.

The properties and the derivations of the Weibull models play a crucial role for estimating the parameters. Proper understanding of the mathematics of these models avoids problems encountered in the method of parameter estimations of the models. This paper provided the most fundamental properties and careful observations of the first and second derivatives of the models. This paper also provides some useful definition of the parameters for initial estimates of the Weibull models, which is also a major requirement for estimating the parameters using any iteration method. Three well-known Forestry data sets are considered to estimate the parameters of these models.

II. Material and methods

The growth models considered for this study are Weibull model with two parameters (6), Weibull model with three parameters (5) and Weibull model with four parameters (4). For these three models consider, w is the dependent growth variable, t is the independent variable, a, b, c and m are parameters to be estimated, \log is the natural logarithm and $\exp(e)$ is the base of the natural logarithms. The properties of

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