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Received 25 May 2021; revised accepted 14 June 2021

doi: 10.18520/cs/v121/i4/570-573

Evaluation of probability distribution functions applied to tree diameter in a mixed uneven Kiker (*Robinia pseudoacacia*) stand of Kashmir Himalaya, India

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Probability distribution is of significance to predict tree distribution and estimate productivity in different ages as well as thinning out in forest stands to ensure optimized and stable stands. Statistical probability distributions, viz. lognormal, Weibull, exponential and gamma were used to fit tree-diameter data generated from the Manasbal forest stand of Kashmir Himalaya, India containing a heterogeneous population of trees with the objective to determine the best probability distribution of tree diameter. To estimate the parameters of the fitted distributions, the method of maximum likelihood was used. The various distributions were evaluated using different goodness-of-fit tests, viz. Kolmogorov–Smirnov, Cramer–von Mises and Anderson–Darling statistics, and the best distribution pertaining to the forest stand was ascertained. Lognormal distribution fitted the data well and could be used in modelling, planning and scheduling the forest stand in the study region.

Keywords: Diameter class, goodness-of-fit statistics, forest stands, probability distribution function, *Robinia pseudoacacia*.

THE genus *Robinia* is noteworthy for its numerous uses. Black locust (*Robinia pseudoacacia*) is part of the Leguminosae family and is known locally as 'Kiker', in Jammu and Kashmir, India. It is a rapidly growing species, making it a primary source of biomass fuel in the region. In many native forests where it occurs, *R. pseudoacacia* dominates early forest regeneration[1]. It is a spiny, deciduous tree of medium size, reaching a height of 25–30 mt and a diameter of 80–90 cm under favourable conditions. Models of forest simulation have been widely used to predict future stand structure. Tree-diameter distribution plays a vital role in simulation modelling. Different probability distributions are being used extensively to model the diameter of trees in the forest stands. Some of the

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most commonly used distributions are Weibull, lognormal, gamma and exponential.

R. pseudoacacia is native to North America, from where it has been introduced into France, Hungary, Belgium, southern Russia, Italy and the Balkan States. In India, it was first introduced in Himachal Pradesh (HP) in 1890 and later in Jammu and Kashmir (J&K) in 1919, largely to reforest the barren hills. It performed well in the outer Himalaya between 1800 and 3000 m, and in the inner Himalaya at elevations as low as 1050 m in HP[2].

Robinia species have a rough brown to dark grey, longitudinally furrowed bark. The young shoots are smooth, purplish-brown, armed with stout triangular spines in pairs, which persist for some years. Leaves are imparipinnate and 10–15 cm long. Petioles are swollen at the base, stipules are transformed in spines, leaflets are oval or elliptic in shape, 9–19 in number and 2.5–5.0 cm long. The flowers are white and fragrant, appear in pendulous axillary racemes up to 20 cm long on current year's shoots. Pods are 2.5–10 cm long and 0.9–1.8 cm broad, flat and dark brown outside, but silvery-white and shining inside bearing 4–16 seeds. The seeds are olive-green to brown, compressed reniform, 5 mm long.

Robinia ranks high in strength and is considered moderately suitable in shape and size. Tests carried out in India show that *Robinia* of Kashmir origin is lighter in weight as well as inferior to its USA counterpart in all its properties and uses. *Robinia* from Srinagar, J&K, can be classified as heavy, moderately strong and very hard timber, suitable for general construction, flooring, light tool handles, wood poles, fence posts, etc[3]. Its retention of shape and size relative to teak was found to be 73%, taking teak as 100% (ref. 4). It is also used as fuelwood.

In Hungary, the main source of honey produced commercially is from *Robinia* crop. The yield of honey per ha at 10 years age of *R. pseudoacaia* was 402 kg; at 15 years 418 kg; at 20 years 407 kg and at 25 years, 369 kg (ref. 5).

Distribution studies of tree diameter play a vital role in modelling and simulation studies. According to Rubin *et al.*[6], diameter distributions can be used to indicate whether the density of smaller trees in a stand is sufficient to replace the current population of large trees, and help assess the potential sustainability of forests. Diameter at breast height (DBH) distribution modelling is usually a two-stage process. A probability density function (pdf) is usually fitted at the first stage to the actual diameter distribution and the pdf parameters are regressed against other measured or a priori known stand attributes (parameter prediction method)[7]. Thomas and Cao[8] developed a diameter distribution model for even-aged stands of European beech in Denmark using Weibull distribution. Parameters of the model were estimated by fitting the cumulative density function using a nonlinear least squares procedure. Fallah *et al.*[9] showed that regression distribution can determine the diameter distribution of trees. Data collection is difficult in many complex forest stands and often results in data violating simple statistical model assumptions.

Using relevant data distributions in complex forest stands offers a significant solution to this perennial challenge. To evaluate the forest schedule and resources, researchers are particularly interested in predicting the diameter distribution of the forests. Additionally, information on forest distribution is necessary for certain growth models and the associated parameters for proper model identification and fitting. In some cases, none of the distributions is appropriate for all ages. Bullock and Boone[10] studied diameter distribution of loblolly pine trees (*Pinus taeda* L.) in Virginia and Northern California, USA. They studied normal, gamma, Weibull and beta distribution for fitting data, and found that sometimes none of the distributions was appropriate for all ages.

The study area, Manasbal is located in Ganderbal district, J&K. The actual location of the Manasbal catchment (Appendix 1) is defined by 34.0°14′–34.0°16′N and 740°40′–740°43′E and has an altitude of about 1551 m amsl. The climate is generally temperate with severe winter extending from December to March. The region faces a wide temperature range from a minimum of –4°C in winter to a maximum of 33°C in summer. The annual precipitation of the area is about 700 mm and most of the precipitation is received in the form of snow during the winter months. The present study was carried out in the plantation block of Manasbal, maintained by the Faculty of Forestry, SKUAST-Kashmir, Benhama. The tree species in the plantation were *Cedrus deodara*, *Cupressus turlosa*, *Robinia pseudoacacia* and *Ulmus villosa*. After a survey of the entire area, trees of *R. pseudoacacia* were enumerated and a database on tree diameter at breast height (DBH) was generated. In total, 646 trees were enumerated and DBH was measured using a Jackson diameter tape at a height of 1.37 m. The 646 trees were grouped into five diameter classes. R studio software (version 3.6.3) was used to analyse the data.

The results revealed that *Robinia* species had a mean diameter of 40.88 cm, with a standard error (mean) of 0.56 and was distributed in the range 15–92. The frequency table and histogram of the diameter classes indicate that the stand is uneven (Table 1 and Figure 1), and the broad range of tree diameter also indicates the same. The distribution is left-skewed indicating that the stand under study is an uneven erratic one. Various distributions belonging to the class of continuous probability distribution were fitted to the diameter data. The estimates obtained on fitting are briefly given here for each distributions. A lognormal distribution is one in which natural log has a normal distribution with parameters μ and δ. Estimates from the fitted lognormal distribution computed in R Studio version 1.0.44 are given in Table 2 and Figure 2 shows the resultant plots for the given distribution.

In Figure 2, the empirical and theoretical density or the kernel plot indicates the distribution of data over continuous interval. The kernel smoothing in the plot allows for a smoother distribution plot by smoothing out the noise. The peak of the density plot indicates the concentration of the values over the interval. Adjacent to the kernel plot is the *Q–Q* (quantile–quantile) plot, drawn by plotting two sets of quantiles against one another as a graphical method for comparing two probability distributions. On the *Q–Q* plot, the reference line is dependent on the location and scale parameters of the theoretical distribution. The intercept and slope are equal to the location and scale parameters respectively. A linear pattern in the points indicates that the given family of distributions reasonably describes the empirical data distribution. The *Q–Q* plot can be used to visually evaluate the similarity of location, scale, and skewness of the two distributions. Similar to the *Q–Q* plot, the *P–P* (probability–probability) plot shows cumulative distribution functions (CDFs) of the two distributions (empirical and theoretical) against each other to compare regions of high probability density (centre of distribution) because in these regions the empirical and theoretical CDFs change more rapidly than in the regions of low probability density. The *P–P* plots can be used to visually evaluate the skewness of the distributions. The concentration of points near the line indicates that both sets of quantiles are from the same distribution, thus suggesting a good fit of lognormal distribution for tree diameter.

The gamma distribution is defined by rate parameter (θ) and shape parameter (k). The estimates for the two parameters are given in Table 3 and Figure 3 shows the resultant plot for the given distribution. The plots indicate a good fit of the gamma distribution to tree diameter, but show some increase in the Akaike's information criterion (AIC) and Bayesian information criterion (BIC) values compared to those of the lognormal distribution.

Exponential distribution is a special type of gamma distribution with rate parameter $\theta = 1/\lambda$ and scale parameter = 1. The estimate for rate parameter is given in Table 4 and Figure 4 shows the resultant plot for the given distribution.

The probability plots for the exponential distribution show a deviation of the points from the line, thus indicating a poor fit of the distribution to tree diameter.

Weibull distribution is a type of continuous probability distribution which is defined by the rate parameter (θ) and Shape parameter (k). The estimates for the parameter are given in Table 5 and Figure 5 shows the resultant plot

Table 1. Frequency table of various tree diameter classes

Class	Frequency	Relative frequency
<20 cm	14	0.022
20–40 cm	340	0.526
40–60 cm	224	0.347
60–80 cm	65	0.101
>80 cm	3	0.005
Total	646	

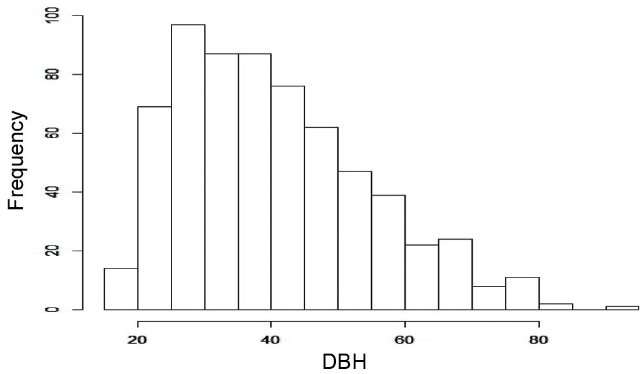

Figure 1. Histogram of tree diameter at breast height.

Table 2. Summary statistics from lognormal distribution

Statistic	Estimate	Standard error
Mean log	3.650	0.0138
Standard deviation log	0.349	0.0097
Log likelihood	–2596.017	
Akaike Information Criterion (AIC)	5196.033	
Bayesian Information Criterion (BIC)	5204.975	

Table 3. Summary statistics from gamma distribution

Statistic	Estimate	Standard error
Shape	8.402	0.458
Rate	0.206	0.011
Log likelihood	–2599.811	
AIC	5203.622	
BIC	5212.563	

Table 4. Summary statistics from exponential distribution

Statistic	Estimate	Standard error
Rate	0.024	0.0009
Log likelihood	–3043.111	
AIC	6088.222	
BIC	6092.693	

Table 5. Summary statistics from Weibull distribution

Statistic	Estimate	Standard error
Shape	3.031	0.089
Rate	45.81	0.630
Log likelihood	–2629.033	
AIC	5262.066	
BIC	5271.008	

Table 6. Parameters of tests for goodness of fit

	Distribution							
	Lognormal		Gamma		Exponential		Weibull	
Goodness-of-fit test	Statistic	*P*-value	Statistic	*P*-value	Statistic	*P*-value	Statistic	*P*-value
Kolmogorov–Smirnov	0.055	0.42	0.068	0.12	0.380	0.04	0.082	0.04
Cramer–von Mises	0.248	0.31	0.352	0.34	25.903	0.05	0.871	0.01
Anderson–Darling	1.559	0.28	2.216	0.21	128.466	0.03	5.966	0.02
AIC	5196.033		5203.622		6088.222		5262.066	
BIC	5204.975		5212.563		6092.693		5271.008	

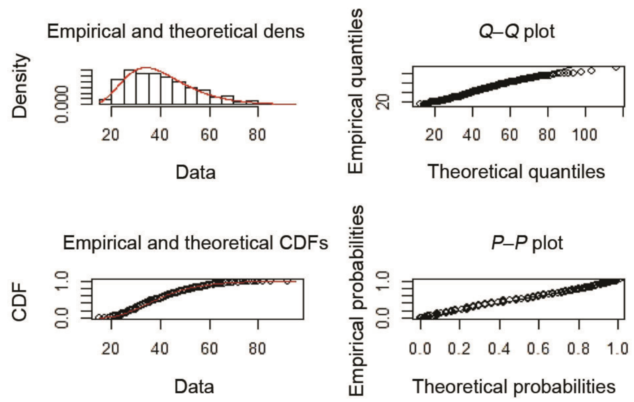

Figure 2. Probability plots from the fitted lognormal distribution.

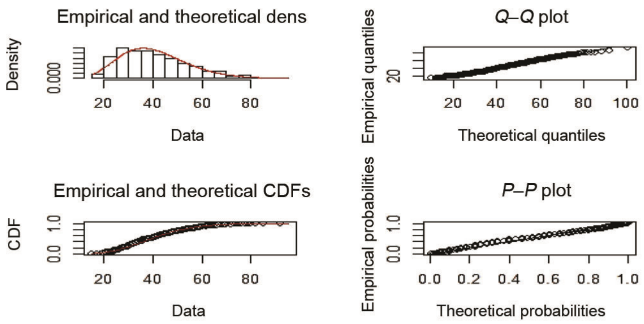

Figure 3. Probability plots from the fitted gamma distribution.

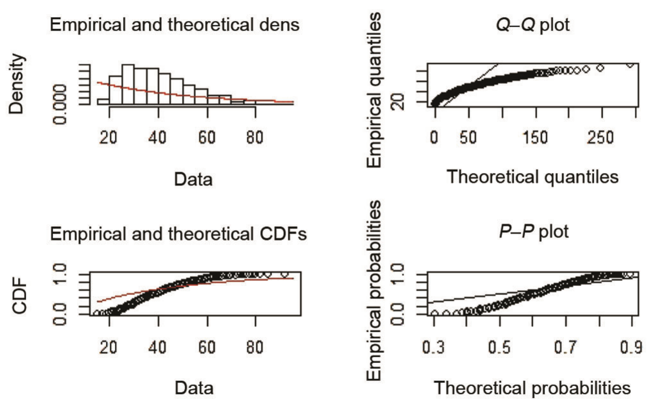

Figure 4. Probability plots from the fitted exponential distribution.

for the given distribution. The probability plots for this distribution fall on the line, indicating a good fit but comparably higher AIC and BIC values compared to lognormal and gamma distribution.

Often in exploratory research on diameter distribution studies, it is practically difficult to select the best probability distribution that fits the tree diameter based upon the probability plots from various distributions. There is no theoretical reason for the fact that a particular distribution model should be used for all situations[11,12]. It seems that the performance of theoretical distributions is affected by the structure (even- and uneven-aged, and pure and mixed stands), density, development stages and habitat conditions of the studied stands[12–15]. Comparison of actual DBH distributions with the theoretical pdf was evaluated by statistical tests, including Kolmogorov–Smirnov, Anderson-Darling and Cramer–von Mises test[8,12,16–18]. The purpose of goodness-of-fit statistics is to measure the distance between the fitted parametric distribution and the empirical distribution, e.g. the distance between the fitted cumulative distribution function F and the empirical distribution function F_{n}. The null and alternative hypothesis of the tests were: H0: The data follow the specified distribution. H1: The data do not follow the specified distribution.

Hypothesis tests of the distribution were performed by examining the probability value associated with each of the goodness-of-fit statistic. Also, the lower values of AIC and BIC are good criteria for assessing the best distribution. Table 6 presents the results from the present study.

The results reveal that only lognormal distribution best describes the distribution of DBH of the *Robinia* species. The study reveals a natural unevenness in the forest stands. Hence estimation of tree distribution in the diameter classes is of great importance and can be used to manage the stands in uneven and aged high forests[9]. Since uneven-aged mixed forests are generally resistant against natural disturbances while providing sustainable production[19], diameter distribution functions have been widely applied to develop forest growth models. Besides, identification and estimation of quantitative characteristics of tree communities are the initial requirements of forest planning. These models provide insight into the

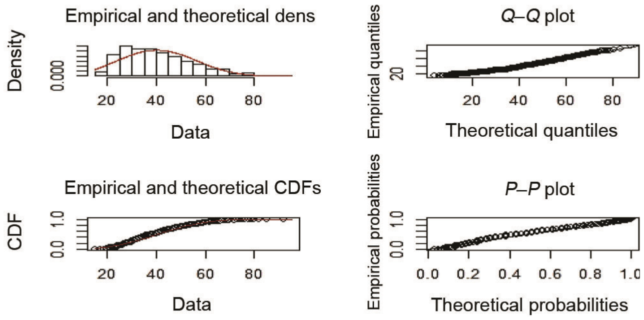

Figure 5. Probability plots from the fitted Weibull distribution.

Appendix 1. *Robinia* Plantation stand (germplasm conservation-cum-experimental site of the Faculty of Forestry, SKUAST-Kashmir) at Manasbal, Jammu and Kashmir, India

complex causal relationships in forest growth and predict growth processes under various ecological conditions[20]. Statistical distributions provide an important means of studying the diameter distribution of trees, beside graphical representations. From the goodness-of-fit tests, it has been confirmed that lognormal distribution can be used for planning and scheduling forest stands in the region to establish stable stands with maximum production.

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ACKNOWLEDGEMENT. We thank Prof. T. H. Masoodi (Dean, Faculty of Forestry Benhama Ganderbal) for guidance.

Received 25 January 2021; revised accepted 6 July 2021

doi: 10.18520/cs/v121/i4/573-577