Agricultural Sciences, 2024, 15, 132-145
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Simulation of *Haloxylon Ammodendron* Stand Basic Diameter Structure Based on Fuzzy Distribution Function

Shaohua Wang[1], Chuanqiang Liu[2], Ting Yang[1]*

[1]College of Economics and Management, Hunan University of Arts and Science, Changde, China
[2]College of Agricultural, Shihezi University, Shihezi, China
Email: *yangting09930907@163.com

How to cite this paper: Wang, S.H., Liu, C.Q. and Yang, T. (2024) Simulation of *Haloxylon Ammodendron* Stand Basic Diameter Structure Based on Fuzzy Distribution Function. *Agricultural Sciences*, **15**, 132-145.
https://doi.org/10.4236/as.2024.151008

Received: December 21, 2023
Accepted: January 20, 2024
Published: January 23, 2024

Abstract

Based on the investigation data of 12 *Haloxylon ammodendron* plots in the south edge of Gurbantunggut Desert, Fuzzy distribution was introduced into the study of *Haloxylon ammodendron* base diameter structure fitting according to the consistency between the characteristics of Fuzzy distribution function and the distribution series of cumulative percentage of stand base diameter, and the fitting precision and effect of Fuzzy distribution function were discussed. The root mean square error RMSE and determination coefficient R^2 values showed that Fuzzy-Γ_1, Fuzzy-Γ_2, Fuzzy-Γ_3, Fuzzy-Γ_4 had good fitting performance, among which Fuzzy-Γ_1 had relatively high fitting precision, and its parameters were closely related to stand age and density, Fuzzy-Γ_2 distribution function was the second, and Fuzzy-Γ_4 distribution function had the worst fitting effect. By introducing a parameter c from the similarity of four distribution function formulas, a generalized Fuzzy distribution function Fuzzy-Γ_5 is obtained. This function shows the highest fitting accuracy. Most of the values of parameter c are near 1 or 2, which shows that the diameter distribution is mainly approximate to Fuzzy-Γ_1 and Fuzzy-Γ_2.

Keywords

Fuzzy Distribution Function, *Haloxylon ammodendron*, Base Diameter Distribution, Stand Factor

1. Introduction

Base diameter is an important characteristic factor in *Haloxylon ammodendron* stand, which has a specific distribution state. It is an important index of stand quality and the basis of establishing stand growth and harvest model. Distribution models of tree size are useful tools for describing tree populations and stands. They are used to evaluate forest quality, predict forest growth, and plan forest harvests to improve forest productivity [1] [2] [3]. Distribution models of tree size can also be used to infer natural and anthropogenic disturbances, forest succession status, and aboveground biomass [4] [5] [6]. Therefore, it is of great theoretical and practical significance to study the diameter distribution, age distribution and the correlation between distribution parameters and stand factors in forest management technology and stand investigation statistics.

As early as the 1950s, foresters began to study DBH distribution models [7] [8] [9]. Diameter structure is an important basic structure of stands. Many classical models have been used to simulate DBH distributions, such as exponential distribution, log-normal distribution, Weibull distribution and gamma distribution models [10] [11] [12] [13]. Various researches show that the DBH distribution of different tree types is quite different, so it is necessary to construct different probability distribution models to fit the DBH distribution [14] [15]. Generally, two methods are used to model the stand structure, namely parametric method and non-parametric method [16] [17]. In the early research of parametric method, probability density function is widely used, but the prediction accuracy of these methods is not satisfactory. In the mid-1990s, foresters applied the Logistic population growth model to describe the cumulative distribution of stand diameter based on the assumption that cumulative frequency increment of diameter was positively correlated with cumulative frequency [18]. Mathematical analysis was conducted on this basis to explore the application of theoretical growth equations in structural models, and good simulation results were obtained. The nonparametric method is a prediction method, which is independent of any distribution function and based on the weighted average distribution of the nearest actual stand diameter [19]. This method has strong flexibility, but it is very complicated. Some of the methods mentioned above have great improvement in simulation accuracy, but there are still some limitations. In this paper, the Fuzzy distribution function is used to describe the stand diameter structure. According to the study, the relationship between the parameter values of the optimal distribution function and the tree factors is analyzed in four common Fuzzy distributions, and the generalized Fuzzy distribution and its change mode are analyzed and fitted.

Haloxylon ammodendron is a perennial shrub xerophyte belonging to Haloxylon genus of Chenopodiaceae. Because *Haloxylon ammodendron* has developed root system and bent main root, it has many characteristics such as drought resistance, high temperature resistance, salt and alkali resistance, wind erosion resistance and cold resistance. It plays an irreplaceable role in preventing wind and sand fixation and restraining desert invasion to oasis, so it is an extremely important wind-proof and sand-fixing plant. Therefore, this paper takes *Haloxylon ammodendron* forest in the south edge of Gurbantunggut Desert as the research object, and introduces Fuzzy distribution function into the investigation data of *Haloxylon ammodendron* sample base diameter to study its base diameter distribution structure, so as to provide scientific basis for the regeneration and restoration of *Haloxylon ammodendron* natural forest and the optimization management and investigation statistics of *Haloxylon ammodendron* plantation.

2. Materials and Methods

2.1. Overview of the Study Area

The study area is located in the southern edge of Gurbantunggut Desert, located at 40˚01'68" - 45˚06'19"N, 85˚59'14" - 86˚18'04"E. Gurbantunggut Desert belongs to temperate arid desert because it is deep inland and far away from the sea. The average relative humidity of air is 50% - 60%, usually below 45% from May to August; the annual precipitation usually does not exceed 150 mm, while the evaporation is as high as 2000 mm, which is 20 - 30 times of precipitation. Most of the desert interior is fixed and semi-fixed sand dunes, with annual rainfall < 120 mm and vegetation coverage of 20% - 45%. Besides Haloxylon, there are Calligonum mongolicum Calligonum mongolicum, red sand (Reaumuriasoongorica) and some short-lived, short-lived plants. According to the distribution characteristics of natural *Haloxylon ammodendron* forest in different desert terrains of Zhungeer Basin, four sites, Jinghe (A), 103 regiment (B), 130 regiment (C) and 148 regiment (D) of Agricultural Sixth Division, were selected respectively. Three sample plots of 140 m × 40 m were selected from each site, totaling 12 sample plots. The diameter of each tree of *Haloxylon ammodendron* in each sample plot was measured, and the basic diameter and stand density of *Haloxylon ammodendron* in each sample plot were investigated and recorded. At the same time, the average values of base diameter and plant height of *Haloxylon ammodendron* were calculated, and the collection information of *Haloxylon ammodendron* forest investigated in the study area was shown in **Table 1**.

2.2. Research Methods

At present, there are not many models for the distribution of base diameter structure of *Haloxylon ammodendron* forest. The Fuzzy distribution model used in the study of DBH and tree height structure of natural forest in forestry was used for reference in selecting suitable models.

A series of basal diameters of *Haloxylon ammodendron* stand with intervals of 2 cm were obtained by measuring basal diameters of *Haloxylon ammodendron* stand, and fuzzy statistics were carried out to obtain a fuzzy array, and then the number of trunk plants corresponding to each diameter class was calculated. Finally, the relative frequency distribution was calculated, and the cumulative distribution sequence in the range of [0, 1] was obtained, which can be defined as a cumulative percentage distribution sequence less than or equal to a certain diameter class. Because this cumulative percentage distribution series presents nonlinear characteristics, we choose the distribution of r type. The four Fuzzy

Table 1. Data collected from *Haloxylon ammodendron* plots in the study area.

Sample plots No.	Stand density n/hm^2	Number of trees n	Average base diameter cm	Average plant height m
A1	1059	593	4.0	1.5
A2	630	353	4.0	1.2
A3	1436	804	2.5	0.8
B1	502	281	6.7	2.0
B2	502	281	6.0	1.8
B3	734	411	9.1	2.3
C1	1507	844	2.2	1.1
C2	305	171	3.4	1.4
C3	739	414	3.9	1.8
D1	591	331	2.8	1.1
D2	996	558	5.4	1.7
D3	398	223	5.6	1.9

distribution functions are Fuzzy-Γ_1, Fuzzy-Γ_2, Fuzzy-Γ_3, Fuzzy-Γ_4 respectively. The mathematical expressions of each distribution are as follows:

$$\text{Fuzzy-}\Gamma_1 = 1 - e^{-k(x-a)} \tag{1}$$

$$\text{Fuzzy-}\Gamma_2 = 1 - e^{-k(x-a)^2} \tag{2}$$

$$\text{Fuzzy-}\Gamma_3 = 1 - e^{-k(x-a)^3} \tag{3}$$

$$\text{Fuzzy-}\Gamma_4 = 1 - e^{-k(x-a)^4} \tag{4}$$

where $k > 0$, $x > a$. Matlab*R*2016a software was used to fit the model parameters, RMSE (root mean square error) and R^2 (goodness of fit judgment coefficient) were used to test the fitness of the model.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{n}} \tag{5}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{\sum_{i=1}^{n}\left(y_i - \bar{y}_i\right)^2} \tag{6}$$

where n is the number of observation points, y_i is the actual measured value, $\hat{y}_i$ is the predicted estimated value, $\bar{y}_i$ is the average value.

Because the collection site is natural *Haloxylon ammodendron* forest, it is impossible to know the age of each stand. The longest method to determine the age and growth quantity of trees is the annual ring measurement of trees. For *Haloxylon ammodendron* in desert habitat, the relationship between age and growth ring is $n = t/m$. The average annual wide growth ring number of *Haloxylon ammodendron* sand type is established by frequency statistics method, and the sand type is 4.8 rings. The wide growth ring model of *Haloxylon ammodendron* population is established through model selection and back-inspection.

$$t = 5.5261r + 2.9039h + 13.9283 \quad (7)$$

where n is age, m is the number of annual wide growth rings, t is the number of total wide growth rings, r is base diameter ($r \geq 1$ cm), h is tree height.

3. Results and Analysis

3.1. Characteristics of Base Diameter Structure of Haloxylon Ammodendron

The basic statistics of 12 *Haloxylon ammodendron* sample plots in the southern edge of Gurbantunggut Desert show (**Table 1**) that the stand density of sample plot No.1 of 130 regiment (C1) is the largest, which is 1507 plants/hm^2. The mean base diameter of each *Haloxylon ammodendron* plot ranged from 2.2 cm to 9.1 cm, among which Jinghe, 103 regiment, 130 regiment and 148 regiment plots ranged from 2.5 cm to 4.0 cm, 6.0 cm to 9.1 cm, 2.2 cm to 3.9 cm and 2.8 cm to 5.6 cm, respectively. The maximum value of basal diameter in plot 3 (B3) of 103 regiment was 9.1 cm, and the minimum value in plot 1 (C1) of 130 regiment was 2.2 cm. The mean value of the base diameter of the population of the four sites is 130 regiment (C) < Jinghe (A) < 148 regiment (D) < 103 regiment (B). The results showed that *Haloxylon ammodendron* base diameter distribution was uniform and concentrated in each habitat plot of 130 regiment (C), and young *Haloxylon ammodendron* trees were dominant.

Figure 1 shows the schema fitted by Matlab for the distribution of various ground diameter classes. Four of the sample plots are randomly selected and displayed in the article. The horizontal point pattern, frequency distribution and relative cumulative frequency diagram are used to reflect the distribution structure of *Haloxylon ammodendron*. It can be seen from the scatter plot that due to the distribution of natural *Haloxylon ammodendron* stand, the field investigation scope is often not limited to the range of 140 × 40 m. According to the graphical representation of the data obtained from the investigation, the actual distribution of *Haloxylon ammodendron* stand is more random distribution structure, and the natural *Haloxylon ammodendron* stand grows densely and has a tight structure. From frequency histogram, it can be seen that the diameter class of *Haloxylon ammodendron* has a peak value between 2 - 8 cm, and accounts for 60% or more of the total number of plants, and the number of large diameter class is relatively stable, which indicates that the ecosystem has certain stability and can maintain natural regeneration. From the relative cumulative frequency diagram, it can be seen that the distribution of base diameter structure of *Haloxylon ammodendron* forest follows the reverse "J" shape. When the diameter class of *Haloxylon ammodendron* reaches 6 - 8 cm, the growth of base

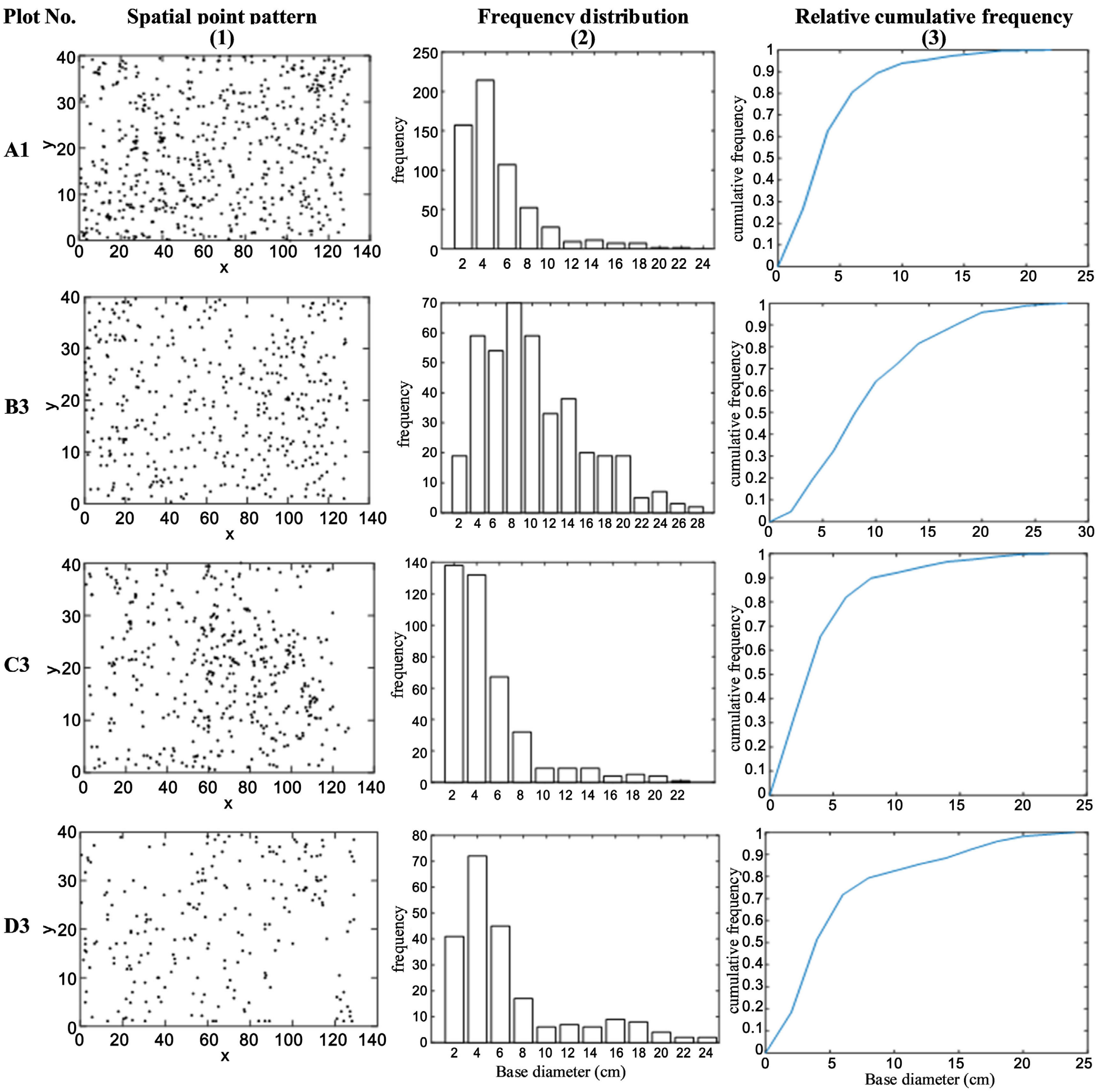

Figure 1. Distribution of base diameters.

diameter of natural *Haloxylon ammodendron* forest is obviously slow or even stagnant, which is consistent with the typical reverse "J" shape law followed by tree different age forest, which indicates that the number of plants in *Haloxylon ammodendron* forest decreases gradually with the increase of diameter class.

3.2. Fuzzy Distribution Fitting of *Haloxylon Ammodendron* Base Diameter Structure

The purpose of this study is to establish the distribution model of *Haloxylon ammodendron* base diameter. In order to establish this model, three sample plots of each area should be integrated and analyzed, and then the total sample plots of the integrated four areas should be summarized into a whole (E) for analysis, as shown in **Figure 2**.

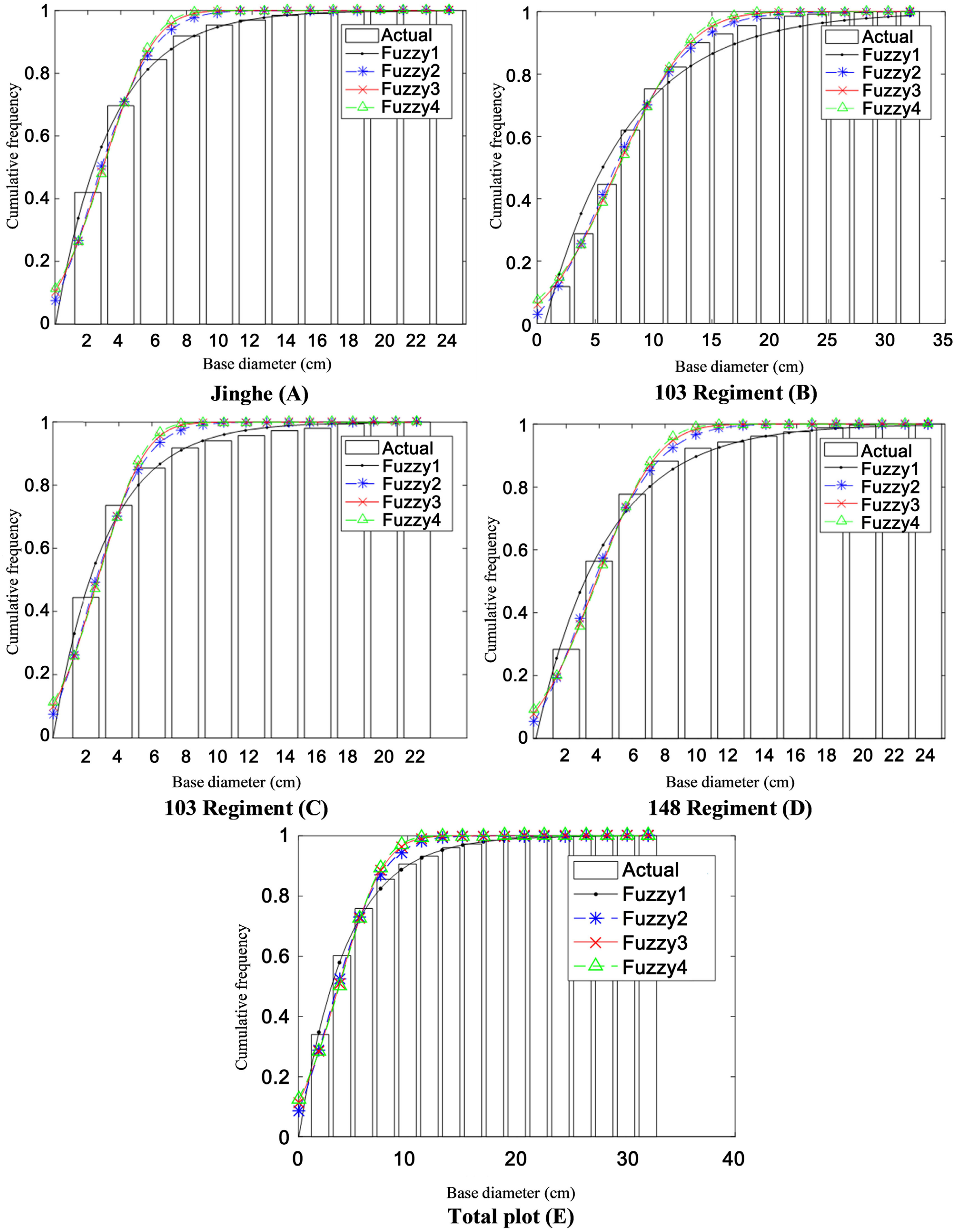

Figure 2. Cumulative distribution and function fit plot of various ground diameter classes.

It can be seen from Table 2 that each parameter of the four Fuzzy distribution functions is deterministic, and the function of these value parameters k and a gradually decreases from Fuzzy-Γ_1 to Fuzzy-Γ_4. Except for B sample plot, the fitting accuracy of the other three sample plots is relatively higher, and their decision coefficients (R^2) are 0.9991, 0.998 and 0.9917 respectively. In the same plot, the decision coefficient of Fuzzy-Γ_1 is obviously higher than that of other distribution functions; In plot B, the decision coefficient of Fuzzy-Γ_2 is higher than that of the other three distribution functions, which indicates that Fuzzy-Γ_2 has better fitting effect and higher fitting precision in this plot. In the total plot (E), the decision coefficient R^2 of Fuzzy-Γ_1 distribution function is 0.9991, which indicates that the fitting precision of this function is higher than that of the other three functions, and it is more suitable for the actual distribution of *Haloxylon ammodendron*. The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire journals, and not as an independent document. Please do not revise any of the current designations.

From the whole point of view, the adaptability of Fuzzy-Γ_1 distribution function is obviously higher than other distribution functions, and the reason why

Table 2. Cumulative distribution and function fit plot of various ground diameter classes.

Sample Plot	Equation	Fuzzy Parameters		R^2	RMSE
		k	a		
A	Fuzzy-Γ_1	0.2977	0.02984	0.9991	0.000987
	Fuzzy-Γ_2	0.03887	−1.412	0.9854	0.01575
	Fuzzy-Γ_3	0.002782	−3.38	0.9757	0.02626
	Fuzzy-Γ_4	0.000141	−5.415	0.9705	0.03179
B	Fuzzy-Γ_1	0.1395	0.6547	0.9775	0.04055
	Fuzzy-Γ_2	0.009606	−1.802	0.9981	0.003347
	Fuzzy-Γ_3	0.0003455	−5.697	0.9935	0.01174
	Fuzzy-Γ_4	8.82E−06	−9.729	0.9903	0.01745
C	Fuzzy-Γ_1	0.3119	0.009195	0.998	0.002009
	Fuzzy-Γ_2	0.04476	−1.314	0.9782	0.02201
	Fuzzy-Γ_3	0.003545	−3.098	0.9671	0.03314
	Fuzzy-Γ_4	0.0001988	−4.938	0.9614	0.03887
D	Fuzzy-Γ_1	0.2337	0.1523	0.9917	0.01014
	Fuzzy-Γ_2	0.02645	−1.429	0.9913	0.01062
	Fuzzy-Γ_3	0.001632	−3.704	0.984	0.01938
	Fuzzy-Γ_4	7.13E−05	−6.061	0.98	0.02427

the optimal distribution function of plot B is Fuzzy-Γ_2 may be that the number of *Haloxylon ammodendron* plants in plot B is too small, while the number of *Haloxylon ammodendron* plants in other four areas is higher than that in plot B, and their optimal distribution functions are all Fuzzy-Γ_1. From this point, it is also confirmed that the optimal distribution function of plot B is Fuzzy-Γ_2 because the number of *Haloxylon ammodendron* plants in plot B is too small. According to statistics, the order of fitting precision of the four fuzzy distributions is Fuzzy-Γ_1 > Fuzzy-Γ_2 > Fuzzy-Γ_3 > Fuzzy-Γ_4.

3.3. Relationship between Parameters *k*, *a* and Age and Density

The decision coefficient of Fuzzy-Γ_1 is relatively high, so the relationship between distribution parameters and forest factors can be studied according to this distribution. To determine the relationship between parameters *k*, *a* and forest age and density, firstly, the distribution status and distribution frequency of different base diameters of each sample plot should be determined, and the relative cumulative frequency of base diameter of each sample plot should be determined by distribution frequency. The 12 plots in the data are all natural *Haloxylon ammodendron* stands, and their age can be determined according to the average base diameter and average plant height. The specific results are as follows:

It can be seen from **Figure 3** that parameters *k* and *a* have obvious decreasing trend with the change of stand age and density. The relationship between parameter *k* and forest age can be expressed by a power function: $k = 7.359x^{-1.578}$, the coefficient of determination (R^2) is 0.9. The relationship between parameter *a* and stand density is polynomial: $a = 8.478\text{e} - 07x^2 - 0.002459x + 1.506$, the coefficient of discrimination was 0.8055, the significant level of variance analysis was 0.05, It is obvious that parameters *k* and *a* are closely related to age and density (**Table 3**).

3.4. Generalized Fuzzy Distribution Function

Four distribution functions as shown in Equations (1)-(4), their mathematical expressions are very similar, but the power exponent arguments are different. The simulation accuracy of the four equations is obviously different when the power exponent is different. By introducing a parameter, a generalized Fuzzy distribution function is obtained, and its mathematical expression is as follows:

$$\text{Fuzzy-}\Gamma_5 = 1 - \text{e}^{-k(x-a)^c}$$

As shown in **Table 4**, the coefficient of determination (R^2) and root mean square error (RMSE) show that Fuzzy-Γ_5 has better simulation performance than the four distributions mentioned above. The value of *c* of this parameter is mostly near 1 and 2, indicating that the cumulative diameter distribution form is mainly represented by Fuzzy-Γ_1 and Fuzzy-Γ_2 on the nearby type. When applying Fuzzy-Γ_5 distribution function to predict the station diameter distribution, the parameter recovery method is adopted.

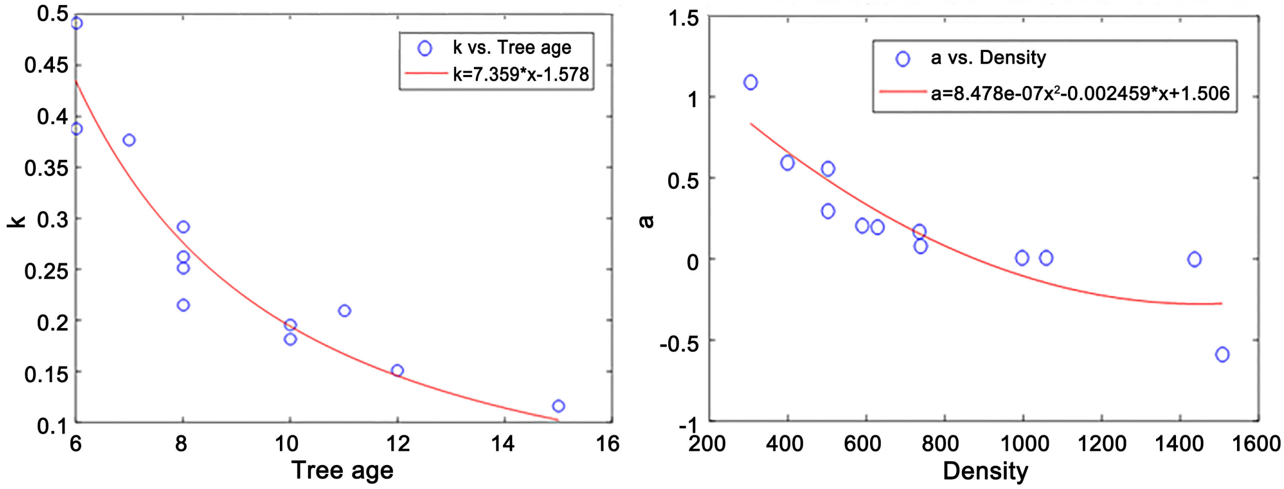

Figure 3. Relationships between parameters *k*, *a* of Fuzzy-Γ_1 and age, density.

Table 3. Tree age, density and Fuzzy-Γ_1 parameter value in various sites.

Sample Plot	Tree Age	Density ($n \cdot hm^{-2}$)	Fuzzy-Γ_1 Parameter Values	
			k	*a*
1	8	1059	0.2513	0.1727
2	8	630	0.2152	−0.5888
3	6	1436	0.3882	0.009813
4	12	502	0.1502	0.5607
5	11	502	0.2094	0.295
6	15	734	0.1154	1.088
7	6	1507	0.4921	−0.004072
8	8	305	0.2919	0.2014
9	8	739	0.2618	0.0807
10	7	591	0.3764	0.006941
11	10	996	0.1955	0.5941
12	10	398	0.1822	0.1979

Table 4. Estimated regression coefficients, R^2, and RMSE for Fuzzy-Γ_5.

Equation	Fuzzy Parameters			R^2	RMSE
	k	*a*	*c*		
Fuzzy-Γ_5	0.0074e−10 - 0.2594	−2.047 - 0.03872	0.5742 - 1.7315	0.9991	0.007062

The final aim of all simulation experiments is to predict future conditions, and the prediction methods are usually scientific, reliable, simple and feasible. For Fuzzy-Γ_1, the simulation accuracy is higher than that of the above fuzzy distributions, and its parameters have close correlation with stand factors. Therefore, the parameter prediction method can be used to predict the distribution of stand diameter, while Fuzzy-Γ_5 derived from four fuzzy distribution functions has better fitting property. For Fuzzy distribution, the future stand diameter distribution can be obtained by effective prediction after the natural thinning model of stand is established by knowing the future stand age and current stand density.

4. Conclusions and Discussions

Based on the investigation data of 12 *Haloxylon ammodendron* plots in the south edge of Gurbantunggut Desert, the distribution characteristics of base diameter structure and model fitting of *Haloxylon ammodendron* were studied. The following conclusions were obtained: 1) The distribution of base diameter of *Haloxylon ammodendron* stand presented an inverse "J" trend, indicating that the stand had good natural regeneration. When the diameter of *Haloxylon ammodendron* reached 6 - 8 cm, the growth of base diameter of natural *Haloxylon ammodendron* forest was obviously slow or even stagnant. 2) The cumulative percentage distribution of the base diameter of *Haloxylon ammodendron* stand is consistent with the graph characteristics of Fuzzy distribution function, which indicates that the structure of base diameter of *Haloxylon ammodendron* stand can be fitted by Fuzzy distribution function. 3) Four Fuzzy distribution functions Fuzzy-Γ_1, Fuzzy-Γ_2, Fuzzy-Γ_3, Fuzzy-Γ_4 all show better fitting performance, among which Fuzzy-Γ_1 has relatively higher fitting precision, its model parameters k, a are closely related to stand age and density, Fuzzy-Γ_2 distribution function is next, Fuzzy-Γ_4 distribution function has the worst fitting performance. 4) According to the similarity of four Fuzzy distribution functions, we introduce a parameter c and obtain a generalized Fuzzy distribution function Fuzzy-Γ_5, which exhibits the highest fitting accuracy. Most of the values of parameter c are near 1 or 2, indicating that the diameter distribution is mainly approximate to Fuzzy-Γ_1 and Fuzzy-Γ_2.

Haloxylon ammodendron forest is a kind of xerophytic shrub with developed roots but slow growth. It is the most extensive and concentrated plant community in Gurbantunggut desert. Its basal diameter distribution shows diversity. in this study, that distribution of base diameter of 12 different natural *Haloxylon ammodendron* stand follows the rule of inverse "J" shape, which is the same as the trend of inverse "J" shape followed by different age trees, that is, with the increase of diameter class, the number of plants corresponding to diameter class of *Haloxylon ammodendron* gradually decreases. When diameter class of *Haloxylon ammodendron* reached 6 - 8 cm, the growth of base diameter of natural *Haloxylon ammodendron* stands obviously presents a slow or even stagnant state, which is the same as the rule shown by different age trees mixed forest. In this study, the peak value of basal diameter distribution structure of natural *Haloxylon ammodendron* forest mainly concentrated in diameter class of 2 - 8 cm, accounting for 65% or more of total number of *Haloxylon ammodendron*, and the number of larger diameter class (≥13 cm) of *Haloxylon ammodendron* was relatively stable, which indicated that the stability of the ecosystem was relatively high and natural regeneration could be maintained. According to the corresponding relationship between mathematical characteristics of cumulative percentile series of stand diameter and distribution range, Fuzzy distribution function is used to model the distribution of base diameter of natural *Haloxylon ammodendron* forest. Because of the different expressions of fuzzy distribution, their simulation characteristics are obviously different. Among the fuzzy functions used, Fuzzy-Γ_4 has the lowest simulation accuracy, and the generalized fuzzy distribution function Fuzzy-Γ_5 with variable parameters has the highest accuracy. The results of parameter analysis show that the parameters of Fuzzy-Γ_1 are closely related to stand age and density. Introducing Fuzzy distribution function into the simulation of stand base diameter distribution of *Haloxylon ammodendron* base diameter is beneficial to correctly recognize and grasp the distribution law of stand base diameter. With the development of base diameter distribution and simulation technology, the combination of stand factors and key characteristics of distribution function is helpful to identify the important factors that cause the difference of simulation characteristics of distribution function, which is of great significance for selecting distribution function.

As a whole, it can be seen that the Fuzzy distribution of this study can effectively simulate the distribution of base diameter of natural *Haloxylon ammodendron* forest in Gurbantunggut Desert, and provide scientific basis for the growth and statistical investigation of natural and artificial *Haloxylon ammodendron* forest. Because of the complexity and diversity of the distribution of base diameter of *Haloxylon ammodendron* forest affected by various internal and external factors, different distribution functions have different fitting effects under different habitat conditions, so it is necessary to select suitable distribution function models according to the actual conditions of each forest. In addition, it is necessary to construct a simpler and more accurate model of base diameter distribution, further analyze and predict the parameter values of base diameter distribution model and the variation law of stand factors, and accurately predict the dynamic distribution of natural *Haloxylon ammodendron* forest in desert.

Acknowledgements

The research was supported by Hunan University of Arts and Sciences Doctoral Research Initiation Project (20BSQD04); Hunan Provincial Natural Science Foundation (2023JJ60168).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Hao, X., Ouyang, W., Zhang, K., Wan, X., Cui, X. and Zhu, W. (2022). Enhanced

Release, Export, and Transport of Diffuse Nutrients from Litter in Forested Watersheds with Climate Warming. *Science of the Total Environment*, **837**, Article ID: 155897. https://doi.org/10.1016/j.scitotenv.2022.155897

[2] Xu, L.X., He, Y.J., Ai, X.R. and He, J. (2024) Sustainable Forest Management Based on Trade-Offs and Synergies of Forest Ecosystem Services. *Acta Ecologica Sinica*, No. 4, 1-13. https://doi.org/10.20103/j.stxb.202303180514

[3] Hyink, D.M. and Jwjr, M. (1983) A Generalized Framework for Projecting Forest Yield and Stand Structure Using Diameter Distributions. *Forest Science*, **29**, 85-95. https://doi.org/10.1093/forestscience/29.1.85

[4] Ekström, A.L., Bergmark, P. and Hekkala, A.M. (2021) Can Multifunctional Forest Land Scapes Sustain a High Diversity of Saproxylic Beetles? *Forest Ecology and Management*, **490**, Article ID: 119107. https://doi.org/10.1016/j.foreco.2021.119107

[5] Ferreira, I.J.M., Campanharo, W.A., Fonseca, M.G., Escada, M.I.S., *et al.* (2023) Potential Aboveground Biomass Increase in Brazilian Atlantic Forest Fragments with Climate Change. *Global Change Biology*, **29**, 3098-3113. https://doi.org/10.1111/gcb.16670

[6] García-Cox, W., López-Tobar, R., Herrera-Feijoo, R.J., Tapia, A., Heredia-R, M., Toulkeridis, T. and Torres, B. (2023) Floristic Composition, Structure, and Aboveground Biomass of the Moraceae Family in an Evergreen Andean Amazon Forest, Ecuador. *Forests*, **14**, Article ID: 1406. https://doi.org/10.3390/f14071406

[7] Shuli, W., Fengshan, L. and Ying, L. (1996). Small-Diameter Korean Pines and Their Roles in Natural Korean Pine Forest. *Journal of Northeast Forestry University*, **7**, 1-7. https://doi.org/10.1007/BF02843235

[8] Coomes, D.A. and Allen, R.B. (2007) Mortality and Tree Size Distributions in Natural Mixed Age Forests. *Journal of Ecology*, **95**, 27-40. https://doi.org/10.1111/j.1365-2745.2006.01179.x

[9] Chen, S., Liu, H., Feng, Z., Shen, C. and Chen, P. (2019) Applicability of Personal Laser Scanning in Forestry Inventory. *PLOS ONE*, **14**, e0211392. https://doi.org/10.1371/journal.pone.0211392

[10] Podlaski, R. and Zasada, M. (2008) Comparison of Selected Statistical Distributions for Modelling the Diameter Distributions in Near-Natural Abies-Fagus Forests in the Świętokrzyski National Park (Poland). *European Journal of Forest Research*, **127**, 455-463. https://doi.org/10.1007/s10342-008-0229-3

[11] de Lima, R.A.F., Batista, J.L.F. and Prado, P.I. (2015) Modeling Tree Diameter Distributions in Natural Forests: An Evaluation of 10 Statistical Models. *Forest Science*, **61**, 320-327. https://doi.org/10.5849/forsci.14-070

[12] Morgenroth, J., Nowak, D.J. and Koeser, A.K. (2020) DBH Distributions in America's Urban Forests—An Overview of Structural Diversity. *Forests*, **11**, 135. https://doi.org/10.3390/f11020135

[13] Pandey, H.P. and Pokhrel, S. (2021). Stocking Density and DBH Distribution of Community Forests in Nepal. *Small-Scale Forestry*, **20**, 145-159. https://doi.org/10.1007/s11842-020-09461-6

[14] Podlaski, R. (2008). Characterization of Diameter Distribution Data in Near-Natural Forests. *Canadian Journal of Forest Research*, **38**, 518-527. https://doi.org/10.1139/X07-190

[15] Haara, A., Maltamo, M. and Tokola, T. (1997) The K-Nearest-Neighbour Method for Estimating Basal-Area Diameter Distribution. *Scandinavian Journal of Forest Research*, **12**, 200-208. https://doi.org/10.1080/02827589709355401

[16] Latifi, H., Nothdurft, A. and Koch, B. (2010) Non-Parametric Prediction and Mapping of Standing Timber Volume and Biomass in a Temperate Forest: Application of Multiple Optical/LiDAR-Derived Predictors. *Forestry*, **83**, 395-407. https://doi.org/10.1093/forestry/cpq022

[17] Watt, M.S., Dash, J.P., Bhandari, S. and Watt, P. (2015) Comparing Parametric and Non-Parametric Methods of Predicting Site Index for Radiata Pine Using Combinations of Data Derived from Environmental Surfaces, Satellite Imagery and Airborne Laser Scanning. *Forest Ecology and Management*, **357**, 1-9. https://doi.org/10.1016/j.foreco.2015.08.001

[18] Niklas, K.J., Midgley, J.J. and Rand, R.H. (2003) Tree Size Frequency Distributions, Plant Density, Age and Community Disturbance. *Ecology Letters*, **6**, 405-411. https://doi.org/10.1046/j.1461-0248.2003.00440.x

[19] Kangas, A. and Maltamo, M. (2000) Calibrating Predicted Diameter Distribution with Additional Information. *Forest Science*, **46**, 390-396. https://doi.org/10.2106/JBJS.F.00001