Forest Systems
31 (2), e008, 9 pages (2022)
eISSN: 2171-9845
https://doi.org/10.5424/fs/2022312-18230
INIA-CSIC

RESEARCH ARTICLE

OPEN ACCESS

Species composition and specific aspects of the Green Tree Retention structure in unmanaged mixed forests in Asturias (northern Spain)

J. Javier Gorgoso-Varela

University of Santiago de Compostela, Campus de Lugo, Lugo, Spain.

Abstract

Aim of study: i) To characterize the species composition and stand variables in a Green Tree Retention (GTR) structure obtained as result of applying an uneven aged silviculture system based on the BDq method; ii) to conduct a biometric study of these components of the GTR.

Study area: Asturias (northern Spain).

Materials and methods: The GTR system included three groups of trees: non-commercial species, trees destined for production of edible fruits *(Castanea sativa)* and veteran trees (with DBH>52.5 cm, established by the BDq method) in 6 strata of the fourth Spanish National Forest Inventory (SNFI4). The method was applied to trees up to DBH at which are then classified as veteran. The other groups are excluded from management. A biometric study of these components was conducted by analysis of the extreme value distributions of maximum and minimum diameters by fitting the Gumbel Cumulative Distribution Function (CDF). The goodness of fit was evaluated with the Kolmogorov-Smirnov statistic *(D_n)*, the Cramér von Mises criterion *(W^2)*, the bias and the mean squared error (MSE).

Main results: The Gumbel CDF generally produced good results, and the best fits were obtained for maximum diameters. The D_n values were generally low or normal. The values of W^2 and the MSE are consistent with the D_n. As the mean value of the biases is always positive, the Gumbel CDF tends to underestimate the real distributions.

Research highlights: The values obtained for the parameters can help in determining several aspects of the structure of the GTR and thus help in forest management decision-making.

Additional key words: ecological system; non-commercial species; *Castanea sativa;* veteran trees

Abbreviations used: CCF (continuous cover forestry); CDF (cumulative distribution function); DBH (diameter at breast height); G (basal area); GEV (generalized extreme value); GTR (green tree retention); IAVC (annual increment in volume with bark); KS (Kolmogorov Smirnov); MSE (mean square error); N (number of trees per hectare); PDF (probability density function); VLE (firewood volume).

Parameters: dg_j (quadratic mean diameter); D_n (KS statistic); Gj (stand basal area); N_j, (number of trees per hectare); v_{ij} (individual tree volume); V_j (volume per hectare); V_{sc} (volume without bark); W^2 (Cramér von Mises criterion); μ (location parameter of the Gumbel function); σ (scale parameter); ξ (shape parameter).

Authors' contributions: This manuscript has one author who conceived and designed the study, performed the study, analyzed the data and wrote the manuscript.

Citation: Gorgoso-Varela, JJ (2022). Species composition and specific aspects of the Green Tree Retention structure in unmanaged mixed forests in Asturias (northern Spain). Forest Systems, Volume 31, Issue 2, e008. https://doi.org/10.5424/fs/2022312-18230

Supplementary material: (Tables S1-S6) accompanies the paper on SJAR's website.

Received: 14 Apr 2021. **Accepted:** 30 May 2022.

Funding agencies/institutions	Project / Grant
Government of Spain, Department of Economy, Industry and Competitiveness	Torres Quevedo Contract (PTQ-16-08445) within the project *Remote^{CCF}: Caracterización estructural y específica de bosques complejos mediante sensores remotos.*

Competing interests: The authors have declared that no competing interests exist.

Correspondence should be addressed to J. Javier Gorgoso-Varela: josejavier.gorgoso@usc.es

Introduction

Continuous cover forestry (CCF), commonly referred to as "close to nature" forestry, is an approach to the sustainable management of forests whereby forest stands are maintained in a permanently irregular structure, which is created and sustained by selecting and harvesting individual trees (Gadow, 2001). In unmanaged mixed stands in the region of Asturias (northern Spain), the lack of silvicultural treatments during the last few decades has led to the general abandonment of these stands, in which timber harvesting is not currently carried out. Unmanaged mixed forest stands in Asturias are predominated by slowly growing deciduous hardwoods including species of the genus *Quercus* and other species with intermediate growth patterns, such as *Castanea sativa*. Natural deciduous forests generally occur in temperate climate zones, although this encompasses a wide diversity of microclimates and bioclimatic types, and 28 different types of forest have been identified (Díaz-González, 2014). Application of CCF systems is recommended in the region because of the steeply sloping topography of the area (which favours erosion) and the extensive protected areas where the stands are of high ecological, recreational and aesthetic value (Gorgoso-Varela *et al.,* 2019). The Green Tree Retention (GTR) system, a concept sometimes included in CCF, proposes maintaining trees or small groups of trees in the stand after clear cutting, to act as wildlife refuges and to help preserve and increase the biodiversity in forest areas (see *e.g.* Rose & Muir, 1997; Vanha-Majamaa & Jalonen, 2001; Valkonen *et al.,* 2002). The economic viability of this silvicultural method has been demonstrated for Scots pine forest in northern Spain (Bravo & Díaz-Balteiro, 2004).

The structural complexity of forest stands has traditionally been equated with the distribution of trees among diameter classes (Palahí *et al.,* 2007), their arrangement in different canopy layers and variation in species composition (Smith, 1986). Variation in tree sizes, both vertically and horizontally, contributes to diversity in microhabitats (Spies & Franklin, 1991). Measures such as GTR, suitable rotations, variable thinning regimes (in relation to time and intensity) and uneven aged management have been proposed in order to create, restore and maintain structural complexity (Hansen *et al.,* 1995; Tappeiner *et al.,* 1997). GTR is aimed at producing larger trees, a greater variability in tree sizes and multi-storey canopies (FEMAT, 1993). Preservation and increased biodiversity in forest areas and maintenance of a stock of old trees and dead wood can also be included as objectives of GTR. Previous studies on GTR have focused on the relationship between levels of GTR and reduction in growth of the young cohort (Rose & Muir, 1997; Zenner *et al.,* 1998) or the relationship between GTR levels and structural complexity (Zenner, 2000). However, biometric study of the specific aspects of the GTR structure has not yet been conducted in field studies.

In uneven aged silviculture, Graz & Gadow (2005) considered trees or species grouped in three classes: principal timber species, non-commercial species (including trees that produce edible fruit and non-commercial trees) and dead trees. We suggest distinguishing four groups in the uneven aged silviculture scheme proposed for the unmanaged mixed forests in Asturias: principal timber species, non-commercial species, trees that produce edible fruits *(C. sativa)* and veteran trees (trees of diameter larger than the maximum cuttable diameter). Dead trees that have not fallen are included in the groups considered. Thus, in the same forests, the GTR ecological system will include trees or species that are not managed under the proposed uneven aged silviculture system, *i.e.* all non-commercial tree species, all sweet chestnut *(C. sativa)* and all veteran trees (DBH>52.5 cm).

Biometric study of the diameter structure of these groups in each plot is complex and inaccurate due the small number of trees included. However, specific aspects of the diameter structure of the different groups can be studied, such as the distribution of the maximum and minimum values by using an extreme value distribution such as the Gumbel distribution (CDF). This approach has previously been used to model the extreme value of diameters and height distributions in forest stands, for different applications (Gorgoso-Varela & Rojo-Alboreca, 2014a; Gorgoso-Varela *et al.,* 2015). The diameters of the veteran trees in the GTR system are important because they determine different types of microhabitats (Larrieu & Cabanettes, 2012). The diameters of sweet chestnut trees influence fruit production, and the diameters of all groups of trees, including the non-commercial trees, affect the structural complexity of the stands. Thus, biometric study of this small component of unmanaged mixed stands in Asturias is of great interest.

The objectives of the present study were to describe the species composition in the GTR system in six strata (1, 2, 3, 21, 24 and 27) of unmanaged mixed forests in Asturias (northern Spain), as defined in the fourth Spanish National Forest Inventory (SNFI4) (MAGRAMA, 2012) and proposed for management under an uneven aged silviculture scheme, and also to study specific aspects of the diameter structure, such as the distribution of maximum and minimum diameters with an extreme value distribution (Fisher & Tippet, 1928), *i.e.* the Gumbel function, for the different groups in the GTR structure (non-commercial species, trees that produce edible fruits and veteran trees).

Material and methods

Data, stand variables and GTR composition

The SNFI4 (MAGRAMA, 2012) is a systematic combined sample of circular sample plots (Loetsch *et al.,* 1973) distributed on a square grid of side 1 km (Table S1 [suppl]). In each plot and for each species, diameters and heights were measured for each sample tree of DBH greater than 7.5 cm, and tree quality, shape and other variables were also recorded. Total number of plots in strata 1 (320 plots), 2 (139 plots), 3 (72 plots), 21 (58 plots), 24 (42 plots) and 27 (40 plots) were considered in the present study.

The species composition was determined and the main stand variables were calculated for the stands conforming the GTR system in the unmanaged mixed forest in Asturias (northern Spain) (Table S2 [suppl]), in accordance with the structure (uneven-aged plots accounted for between 34.7-62.5% of the plots, two-aged plots between 14.4-27.6% and even-aged plots between 5-19%) and the composition of the main stand (see Table S3 [suppl]). The number of trees per hectare *(N_j)*, the stand basal area *(G_j)* and the quadratic mean diameter *(dg_j)* were calculated with all trees in the jth plot. The stand volume per hectare *(V_j)* was calculated as the sum of each individual tree volume *(v_{ij})* obtained from the SNFI4 equations for each species. Furthermore, the total values of IAVC (annual increment in volume with bark: $m^3 \cdot ha^{-1} \cdot year^{-1}$), total volume without bark V_{sc}: $m^3 \cdot ha^{-1}$ and VLE (firewood volume: $m^3 \cdot ha^{-1}$) for all strata are also shown in Table S2 [suppl].

The Gumbel CDF was fitted to maximum and minimum diameter data from the GTR system (non-commercial tree species, *C. sativa* and veteran trees). The non-commercial species present in each stratum are listed in Table S4 [suppl]. Sweet chestnut *(C. sativa)* and veteran trees are included in two different groups (Tables S5 and S6 [suppl]).

Model fitting

The Gumbel distribution

The Gumbel distribution is an extreme value distribution derived from the Generalized Extreme Value (GEV) distribution. Extreme Value Distributions were first derived by Fisher & Tippet (1928) to describe forms of the frequency distribution of the largest or smallest member of a sample. The GEV distribution has the following CDF for a random variable *x* (Eq. 1):

$$F(x,\mu,\sigma,\xi) = exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{\frac{-1}{\xi}}\right\};\quad \text{for } 1+\xi\left(\frac{x-\mu}{\sigma}\right)>0 \quad [1]$$

where μ is the location parameter, σ is the scale parameter and ξ is the shape parameter. The ξ governs the tail behaviour of the distribution. The sub-families defined by $\xi = 0$, $\xi > 0$ and $\xi < 0$ correspond to the Gumbel (type I), Fréchet (type II) and Weibull (type III) families respectively, although the reversed Weibull is the model used to link the three distributions in the GEV.

The probability density function (PDF, Eq. 2) and the cumulative distribution function (CDF, Eq. 3) (Gumbel, 1954) are formulated for a random variable *x,* as follows:

$$PDF: f(x,\mu,\beta) = \frac{1}{\beta}exp[-(z+exp(-z))]$$
$$where\ z = \frac{x-\mu}{\beta};\ -\infty < x < \infty \quad [2]$$

$$CDF: F(x;\mu,\beta) = exp\left[-exp\left(-\frac{x-\mu}{\beta}\right)\right];\quad -\infty < x < \infty \quad [3]$$

where μ is the location parameter, β is the scale parameter estimated with equation [4], and the standard deviation (σ) is calculated as

$$\sigma=\beta\pi/\sqrt{6} \quad [4]$$

The function corresponding to the Gumbel distribution (type I) with $\xi = 0$, was fitted using the location parameter *($\hat{\mu}$)* recovered from the experimental mean *($\bar{d}$)* and standard deviation *(σ)* of the distributions. Thus, the method of moments using the first and the second moments of the distributions (mean $\bar{d}$ and variance σ^2) were applied, by using the following expression (Eq. 5):

$$\bar{d} = \hat{\mu} + \beta\gamma \quad [5]$$

where β is the scale parameter obtained from σ by solving Eq. [4], γ is the Euler-Mascheroni constant, and Eq. 5 is solved by $\hat{\mu}$.

$$\gamma = \lim_{n\to\infty}\left(\sum_{k=1}^{n}\frac{1}{k} - \ln(n)\right) = \int_1^{\infty}\left(\frac{1}{\lfloor x\rfloor} - \frac{1}{x}\right)dx \approx 0.577215 \quad [6]$$

The Gumbel CDF was used to describe the distributions of maximum and minimum diameters of the trees in each plot included into the three groups considered in the GTR scheme: non-commercial species, *C. sativa* and veteran trees (DBH>52.5 cm).

Goodness of fit evaluation

The consistency of the Gumbel CDF was evaluated using the Kolmogorov-Smirnov (KS) statistic *(D_n)*, Cramér von Mises criterion *(W^2)*, bias and mean squared error (MSE).

For a given cumulative distribution function *F(x)*, $D_n = sup_x |F_n(x) - F_0(x)|$, where supx is the supremum of the set of distances. This value was calculated as follows (Cao, 2004: Eq. 7):

$$D_n = max\{max_{1\le i\le n_i}[F_n(x_i) - F_0(x_j)], max_{1\le i\le n_i}[F_0(x_j) - F_n(x_{i-1})]\} \quad [7]$$

where the cumulative observed frequency $F_n(x_i)$ is compared with the cumulative estimated frequency $F_0(x_j)$.

The Cramér von Mises criterion *(W^2)* is a measure of the square of the distance between the empirical distribution and the cumulative theoretical distribution (Wang, 2005; Eq. 8):

$$W^2 = \sum_{i=1}^{n}\left\{\hat{F}(x_i) - \frac{(i-0.5)}{n}\right\}^2 + \frac{1}{12n} \quad [8]$$

where $\hat{F}(x_i)$ is the cumulative theoretical distribution in the diameter class *i* and *n* is the number of diameter classes.

The bias and the MSE were also used as goodness-of-fits measures and were expressed as follows (Eqs. 9, 10):

$$Bias = \frac{\sum_{i=1}^{N} Y_i - \hat{Y}_i}{N} \quad [9]$$

$$MSE = \frac{\sum_{i=1}^{N}(Y_i - \hat{Y}_i)^2}{N} \quad [10]$$

where Y_i is the relative frequency of trees observed value in each diameter class, $\hat{Y}_i$ is the theoretical value predicted by the model, and *N* is the number of diameter classes.

The bias and MSE values were calculated for each fit as the mean relative frequency of trees.

Results

The species (trees and shrubs) composition and the main stand variables for the non-commercial group of species in the GTR structure, for each stratum of the SNFI4 studied (Table S4 [suppl]) showed that Stratum 1 included 8 species, the most abundant of which was the shrub common hazel *(C. avellana),* with 138.79 trees·ha^{-1} (42.8% of the basal area (G) of the non-commercial species). Stratum 2 included 8 species, the most abundant of which were common hazel, with 37.06 trees·ha^{-1} (12.1% of G), and holly *(Ilex aquifolium),* with 32.08 trees·ha^{-1} (20.1% of G). Stratum 3 also included 8 species, the most abundant of which were common hazel, with 38.33 trees·ha^{-1} (18.9% of G), rowan *(Sorbus aucuparia),* with 31.42 trees·ha^{-1} (18.2% of G), and holly, with 30.57 trees·ha^{-1} (24.5% of G). Stratum 21 included 6 species, of which rowan was the most abundant, with 23.30 trees·ha^{-1} (49.3% of G). Stratum 24 (5 species) included common hazel, with 97.41 trees·ha^{-1} (26.7% of G), and pussy willow *(Salix caprea),* with 82.04 trees·ha^{-1} (51.2% of G), and stratum 27 (7 species) included common hazel, with 214.70 trees·ha^{-1} (51.5% of G).

The main stand variables for the second group in the GTR structure, *i.e.* sweet chestnut *(C. sativa)* trees destined for fruit production (Table S5 [suppl]) showed that sweet chestnut was the most abundant tree in stratum 1, with 174.80 trees·ha^{-1} (30% of the total G of the stratum), followed by stratum 2, with 94.16 trees·ha^{-1} (23.7% of G). *C. sativa* was least abundant in stratum 24, with 14.34 trees·ha^{-1} (4.8% of G), and stratum 27, with 15.71 trees·ha^{-1} (9.6% of G). The stand variables (N, G and d_g) for the third group in the GTR structure, *i.e.* the veteran trees (DBH>52.5 cm) including all species in the strata except *C. sativa* (veteran trees of which were included in the previous group), are shown in Table S6 [suppl]. The largest number of veteran trees were present in stratum 1, with 6.09 trees·ha^{-1} and G=2.51 m^2·ha^{-1}, while the lowest number occurred in stratum 21, with 1.14 trees·ha^{-1} and G=0.32 m^2·ha^{-1}. The quadratic mean diameters varied between 58.8 cm in stratum 21 and 81.17 cm in stratum 3. The descriptive statistics (mean, standard deviation, maximum and minimum) of the samples of diameters used in the fits with the Gumbel CDF are shown in Table 1.

Table 1. Main descriptive statistics of the distributions studied for the three groups in the GTR system.

DBH	Str	Mean	SD	Max	Min	Str	Mean	SD	Max	Min
					Non-commercial species					
Max	**1**	20.70	10.86	69.10	7.50	**21**	20.88	11.20	47.00	7.65
	2	22.63	11.84	72.60	7.55	**24**	27.47	17.33	80.90	7.70
	3	20.53	10.11	51.90	8.90	**27**	21.72	12.56	67.40	7.80
Min	**1**	10.93	4.66	31.85	7.50	**21**	13.67	9.48	47.00	7.65
	2	13.42	8.64	43.25	7.50	**24**	15.11	12.25	61.70	7.50
	3	10.66	4.90	25.15	7.50	**27**	11.09	6.11	29.65	7.50
					Castanea sativa					
Max	**1**	59.18	38.48	219.90	7.70	**21**	39.71	31.92	113.60	7.80
	2	55.88	37.18	187.80	12.30	**24**	41.49	21.27	95.80	22.75
	3	59.92	35.71	148.80	17.40	**27**	56.70	44.24	149.60	15.40
Min	**1**	20.31	16.31	104.40	7.55	**21**	26.83	28.78	113.60	7.55
	2	22.08	15.58	89.10	7.50	**24**	31.10	21.23	93.60	8.35
	3	33.57	27.72	111.40	7.80	**27**	47.50	48.12	149.60	12.60
					Veteran trees					
Max	**1**	75.15	23.18	166.20	52.80	**21**	60.45	5.35	70.00	53.65
	2	75.92	18.72	142.20	53.45	**24**	69.01	20.91	141.90	52.75
	3	75.91	19.23	120.90	53.60	**27**	77.25	16.95	112.30	55.35
Min	**1**	62.18	13.23	144.20	52.50	**21**	57.66	3.03	62.85	53.65
	2	63.56	14.93	142.20	52.55	**24**	58.96	7.78	83.10	52.60
	3	63.43	15.29	120.90	52.60	**27**	67.70	15.44	112.30	53.45

DBH: diameter at breast height. Str: stratum.

Table 2. Parameters of the Gumbel function obtained and number of data used in each fit (in brackets).

DBH	Str	*μ*	*β*	Str	*μ*	*β*	Str	*μ*	*β*
				Non-commercial species					
Max	**1 (176)**	15.813	8.468	**3 (34)**	15.985	7.888	**24 (31)**	19.676	13.513
	2 (72)	17.309	9.231	**21 (18)**	15.843	8.733	**27 (28)**	16.072	9.797
Min	**1 (176)**	8.831	3.641	**3 (34)**	8.462	3.821	**24 (31)**	9.599	9.555
	2 (72)	9.539	6.738	**21 (18)**	9.411	7.392	**27 (28)**	8.344	4.765
				Castanea sativa					
Max	**1 (197)**	41.860	30.008	**3 (34)**	43.850	27.844	**24 (15)**	31.918	16.589
	2 (65)	39.147	28.989	**21 (20)**	25.341	24.895	**27 (10)**	36.792	34.499
Min	**1 (197)**	12.964	12.722	**3 (34)**	21.101	21.617	**24 (15)**	21.550	16.551
	2 (65)	15.065	12.154	**21 (20)**	13.879	22.442	**27 (10)**	25.850	37.517
				Veteran trees					
Max	**1 (164)**	64.724	18.076	**3 (24)**	67.261	14.996	**24 (19)**	59.604	16.306
	2 (52)	67.497	14.599	**21 (8)**	58.047	4.174	**27 (16)**	69.629	13.219
Min	**1 (164)**	56.229	10.314	**3 (24)**	56.546	11.928	**24 (19)**	55.459	6.066
	2 (52)	56.841	11.646	**21 (8)**	56.298	2.363	**27 (16)**	60.751	12.039

DBH: diameter at breast height. Str: stratum. *μ:* location parameter. *β:* scale parameter.

The parameters obtained for the Gumbel CDF and the number of data in each fit (in brackets), which is less than the total number of plots of the strata because many plots do not have trees in the three groups of the GTR, are shown in Table 2. Logically, the location parameter *(μ)* yielded the lowest values for non-commercial species, in accordance with the small dimensions of the trees (see Table 1), and the greatest for veteran trees, in accordance with their larger dimensions (see Table 1). The scale parameter *(β)* was related to the range of diameters and it had the largest values for the group of *C. sativa*. The values of the statistics used to test the goodness of fits of the Gumbel CDF to the extreme values of diameters (maximum and minimum) were calculated (Table 3): Kolmogorov-Smirnov (KS) statistic (D_n), Cramér von Mises criterion (W^2), bias and mean squared error (MSE). The D_n values were generally low or normal. Low values with $D_n \leq 0.150$ occurred in 15 out of 36 cases, normal values ($0.150 < D_n \leq 0.200$) occurred in 10 cases and high values of D_n ($D_n > 0.200$) occurred in 11 cases. The values of W^2 and the MSE are consistent with the D_n. As the mean value of the biases is always positive, the Gumbel CDF tends to underestimate the real distributions (*i.e.* it produces positive biases) (see Table 3 and Fig. 1). However, bias may be less useful than other statistics because errors with different signs can be compensated. In general, the best fits were obtained for the distributions of maximum diameters and the worst fits for the distributions of minimum diameters. There were no great differences in the fits for the three groups considered: non-commercial species, *C. sativa* and veteran trees.

Figure 1 shows the observed distributions and the distributions fitted by the Gumbel CDFs for maximum and minimum diameters in non-commercial species (stratum 2), *C. sativa* (stratum 3) and veteran trees (stratum 27). The best fits for the maximum diameters are shown in the figure, and the tendency of the Gumbel to underestimate the observed extreme distributions can be observed.

Discussion

The GTR system proposes maintaining individual trees or small groups of trees in the stand after felling as wildlife refuges and to help preserve or even increase the biodiversity in forest areas (Rose & Muir, 1997; Vanha-Majamaa & Jalonen, 2001). In accordance with the silviculture scheme proposed for the unmanaged mixed stands in Asturias (northern Spain) (Gorgoso-Varela *et al.,* 2019), the GTR system is formed by three different groups of trees: non-commercial species, trees that produce edible fruit *(C. sativa)* and veteran trees. The system was characterized in regard to species composition and stand variables for the non-commercial tree species. Sweet chestnut *(C. sativa)* trees are currently present as coppice, and a suitable management scheme is required to yield large trees suitable for producing good quality fruit and for applying the GTR system to produce wildlife refuges with a variety of microhabitats. Use of the BDq method (Guldin, 1991; Brzeziecki & Kornat, 2011) is proposed here as an uneven aged management method in which consideration of the factor D (maximum cuttable diameter) enables selection

Table 3. Statistics used for testing the goodness of fits of the Gumbel distribution.

DBH	Str	D_n	W^2	bias	MSE	Str	D_n	W^2	bias	MSE
					Non-commercial species					
Max	**1**	0.082	0.049	0.0086	0.0007	**21**	0.174	0.153	0.0105	0.0036
	2	0.109	0.041	0.0078	0.0006	**24**	0.116	0.101	0.0087	0.0013
	3	0.155	0.095	0.0142	0.0021	**27**	0.153	0.122	0.0108	0.0019
Min	**1**	0.211	0.128	0.0333	0.0049	**21**	0.284	0.400	0.0328	0.0097
	2	0.160	0.226	0.0313	0.0060	**24**	0.163	0.296	0.0320	0.0053
	3	0.305	0.212	0.0447	0.0109	**27**	0.263	0.249	0.0473	0.0106
					Castanea sativa					
Max	**1**	0.076	0.165	0.0033	0.0007	**21**	0.200	0.589	0.0087	0.0054
	2	0.081	0.144	0.0052	0.0008	**24**	0.143	0.314	0.0152	0.0042
	3	0.123	0.249	0.0031	0.0018	**27**	0.146	0.424	0.0097	0.0031
Min	**1**	0.165	0.335	0.0160	0.0034	**21**	0.264	1.150	0.0294	0.0107
	2	0.102	0.122	0.0134	0.0014	**24**	0.190	0.380	0.0099	0.0044
	3	0.142	0.296	0.0128	0.0028	**27**	0.304	1.341	0.0225	0.0097
					Veteran trees					
Max	**1**	0.131	0.170	0.0106	0.0014	**21**	0.146	0.065	0.0169	0.0033
	2	0.095	0.075	0.0066	0.0008	**24**	0.181	0.308	0.0194	0.0034
	3	0.103	0.092	0.0055	0.0013	**27**	0.120	0.100	0.0020	0.0016
Min	**1**	0.211	0.307	0.0161	0.0032	**21**	0.274	0.108	0.0284	0.0099
	2	0.206	0.259	0.0175	0.0028	**24**	0.216	0.140	0.0246	0.0042
	3	0.220	0.450	0.0249	0.0065	**27**	0.168	0.197	0.0160	0.0032

DBH: diameter at breast height. Str: stratum. D_n: Kolmogorov-Smirnov statistic. W^2: Cramér von Mises criterion. MSE: mean squared error.

of veteran GTR trees. This method always establishes the D value, and a value of 52.5 cm was considered for these stands on the basis of similar studies in conifers (Brzeziecki & Kornat, 2011; Drozdowski *et al.,* 2014). Thus, veteran trees were considered those trees of diameter larger than 52.5 cm. However, the distribution of the maximum (DBH) can guide silvicultural operations aimed at complying with the BDq method, as managers will have an estimation of the probability that trees will exceed the maximum DBH established. Live veteran trees are very important for the presence of different microhabitats in *Fagus sylvatica* (Larrieu & Cabanettes, 2012): cavities with mould (DBH>41 cm), empty cavities (DBH>41 cm), saproxylic fungi (DBH=100 cm), dendrothelms (DBH>43 cm), missing bark (DBH=110 cm) and cracks (DBH=72 cm). These diameter values were generally surpassed in the stands under study (Table 1). On the other hand, dead wood is also an important component of the GTR (WWF, 2004). However, no specific group of dead wood was considered, and these trees were included in the three groups formed because the SNFI4 provides little information about them.

Specific aspects of the structure of the GTR were described for each group (non-commercial, *C. sativa* and veteran trees). The distributions of the minimum and maximum diameters were described using an extreme value distribution, *i.e.* the Gumbel function. Parameters of the Gumbel function provide information about the distribution of these specific aspects. High values of the location parameter *(μ)* indicate displacement of the PDF to the right, and higher values of the scale parameter *(β)* indicate a larger range and flattening of the PDF. It is important clarifying that the estimators for the maximum and the minimum diameters are not unbiased and depend on the plot size in the SNFI4. For larger plots, more data would also have been used to obtain the parameters of the distribution. The distributions themselves would have been different and the modelled distributions would inevitably underestimate the maximum and the minimum values, although this is not the same as the bias observed when fitting the distributions.

The values of D_n obtained were usually below 0.20, within the range of results obtained in fits of diameter distributions of trees in previous studies (Cao, 2004; Gorgoso-Varela & Rojo-Alboreca, 2014b). The latter authors introduced the extreme value distributions in the field of forestry fitting the Gumbel and the Weibull functions to extreme value of diameter distributions (Gorgoso-Varela & Rojo-Alboreca, 2014a) and the Gumbel, Weibull and Fréchet functions to extreme value of heights distributions

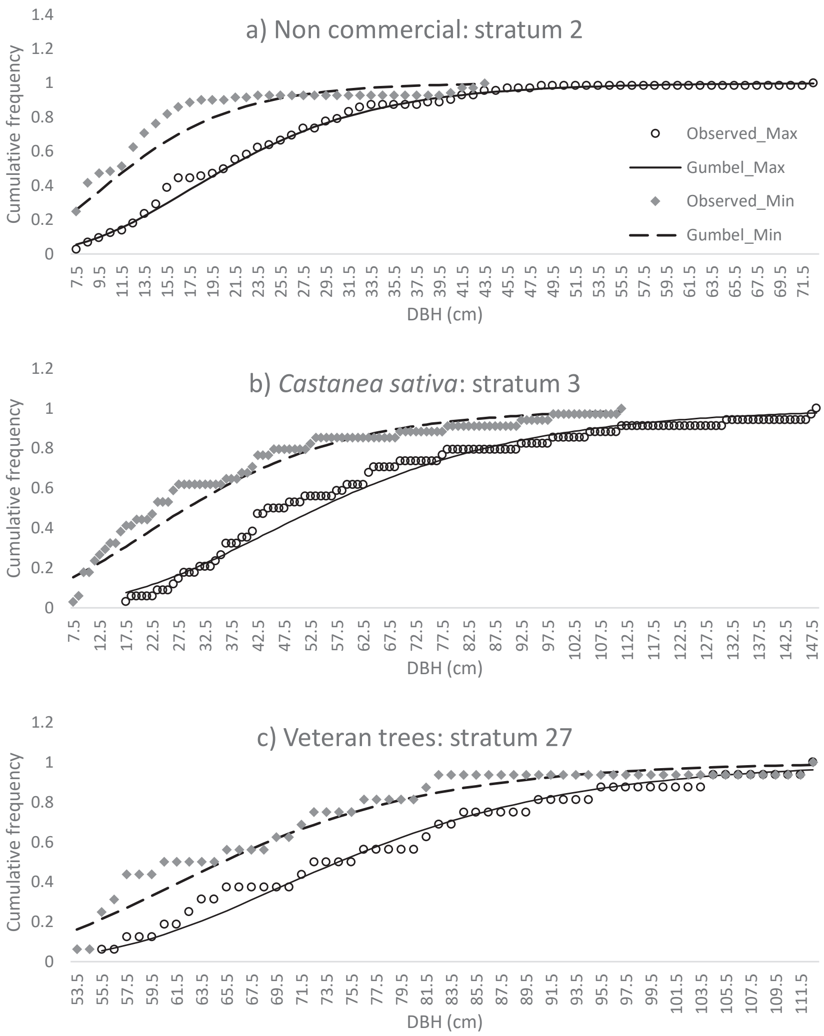

Figure 1. Observed distributions and distributions fitted by the Gumbel CDFs of maximum and minimum diameters in non-commercial species − stratum 2 (a), *Castanea sativa* − stratum 3 (b) and veteran trees − stratum 27 (c).

(Gorgoso-Varela *et al.,* 2015). The results for the Gumbel function are consistent with those of previous studies, and this function provided better fits for the extreme maximum diameters than for minimum diameters. For the distributions of maximum diameters, these authors always obtained values of D_n lower than 0.10 and the values were generally lower than in the present study for both the Gumbel and Weibull distributions. However, for extreme value of heights distributions (Gorgoso-Varela *et al.,* 2015) similar values were obtained with the Gumbel function for the distributions of maximum and minimum tree heights.

In conclusion, the species composition of the GTR system formed by applying the management method proposed (Gorgoso-Varela, unpublished) for uneven aged, unmanaged mixed stands in Asturias (northern Spain) is described. The GTR was composed by three different groups of trees: non-commercial species, trees that produce edible fruit *(Castanea sativa)* and veteran trees (DBH>52.5 cm). Owing to the small number of trees included in the GTR system, specific aspects of the structure of these three groups (distributions of maximum and minimum diameters) were characterized by the extreme value Gumbel CDF. The parameters obtained by the function provide information that can help in making management decisions for these stands.

References

Bravo F, Díaz-Balteiro L, 2004. Evaluation of new silvicultural alternatives for Scots pine stands in northern Spain. Ann For Sci 61: 163-169. https://doi.org/10.1051/forest:2004008

Brzeziecki B, Kornat A, 2011. Application of the BDq method in uneven−aged stands silviculture. Sylwan 155(9): 589-598.

Cao Q, 2004. Predicting parameters of a Weibull function for modeling diameter distribution. For Sci 50(5): 682-685.

Crecente-Campo F, Tomé M, Soares P, Diéguez-Aranda U, 2010. A generalized nonlinear mixed-effects height-diameter model for *Eucalyptus globulus* L. in northwestern Spain. For Ecol Manage 259: 943-952. https://doi.org/10.1016/j.foreco.2009.11.036

Díaz-González TE, 2014. El paisaje vegetal de Asturias en el contexto bioclimático y biogeográfico de la Península Ibérica. Real Instituto de Estudios Asturianos, Oviedo. 141 pp.

Drozdowski S, Andrzejczyk T, Bielak K, Buraczyk W, Gawron L, 2014. Silvicultural planning in spruce mire forests by the means of the BDq method. Sylwan 158(10): 733-742.

FEMAT, 1993. Forest ecosystem management: an ecological, economic, and social assessment. For Ecosyst Manage Assess Team, US Forest Service. Washington, DC.

Fisher RA, Tippett LHC, 1928. Limiting forms of the frequency distribution of the largest or smallest member of a sample. Math Proc Cambridge Philos Soc 24: 180-190. https://doi.org/10.1017/S0305004100015681

Gadow Kv, 2001. Orientation and control in CCF systems. In: Continuous Cover Forestry. Assessment, Analysis; Scenarios; Gadow Kv, Nagel J & Saborowski J (eds). Int IUFRO Conf, 19-21 Sept, Göttingen, Germany, pp: 211-217.

Gorgoso-Varela JJ, Rojo-Alboreca A, 2014a. Use of Gumbel and Weibull functions to model extreme values of diameter distributions in forest stands. Ann For Sci 71: 741-750. https://doi.org/10.1007/s13595-014-0369-1

Gorgoso-Varela JJ, Rojo-Alboreca A, 2014b. A comparison of estimation methods for fitting Weibull and Johnson's SB functions to pedunculate oak *(Quercus robur)* and birch *(Betula pubescens)* stands in northwest Spain. Forest Syst 23(3): 500-505. https://doi.org/10.5424/fs/2014233-04939

Gorgoso-Varela JJ, García-Villabrille JD, Rojo-Alboreca A, 2015. Modeling extreme values for height distributions in *Pinus pinaster, Pinus radiata* and *Eucalyptus globulus* stands in northwestern Spain. iForest-Biogeosci Forest 9: 23-29. https://doi.org/10.3832/ifor1447-008

Gorgoso-Varela JJ, Alonso-Ponce R, Rodríguez-Puerta F, Lizarralde I, 2019. Application of the BDq method to complex structures of natural mixed forests in Asturias (Northern Spain). Int Sci Conf: Forests in Science, Practice and Education. Varsovia, 18-19 Jun.

Graz FP, Gadow Kv, 2005. Application of a stem number guide curve for sustainable harvest control in the dry woodland Savanna of northern Namibia. South Afr Forest J 204: 1-8. https://doi.org/10.2989/10295920509505225

Guldin JM, 1991. Uneven-aged BDq regulation of Sierra Nevada mixed conifers. West J Appl Forest 6(2): 27-32. https://doi.org/10.1093/wjaf/6.2.27

Gumbel EJ, 1954. Statistical theory of extreme values and some practical applications. Applied Mathematics Series, 33. US Dept. of Commerce, National Bureau of Standards.

Hansen AJ, Garman SL, Weigand JF, Urban DL, McComb WC, Raphael MG, 1995. Alternative silvicultural regimes in the Pacific Northwest: simulations of ecological and economic effects. Ecol Appl 5: 535-554. https://doi.org/10.2307/1941965

Larrieu L, Cabanettes A, 2012. Species, live status, and diameter are important tree features for diversity and abundance of tree microhabitats in subnatural montane beech-fir forests. Can J For Res 42: 1433-1445. https://doi.org/10.1139/x2012-077

Loetsch F, Zöhrer F, Haller KE, 1973. Forest inventory 2. Verlagsgesellschaft. BLV. Munich. 469 pp.

MAGRAMA, 2012. Cuarto Inventario Forestal Nacional del Principado de Asturias. Ministerio de Agricultura, Alimentación y Medio Ambiente, Spain. 59 pp.

Palahí M, Pukkala T, Blasco E, Trasobares A, 2007. Comparison of beta, Johnson's SB, Weibull and truncated Weibull functions for modelling the diameter distribution of forest stands in Catalonia (northeast of Spain). Eur J Forest Res 126: 563-571. https://doi.org/10.1007/s10342-007-0177-3

Rose CR, Muir PS, 1997. Green-tree retention: Consequences for timber production in forests of the Western Cascades, Oregon. Ecol Appl 7: 209-217. https://doi.org/10.1890/1051-0761(1997)007[0209:GTRCFT]2.0.CO;2

Smith DM, 1986. Practice of silviculture, 8th edition. John Wiley & Sons. NY, USA.

Spies TA, Franklin JF, 1991. The structure of natural, young, mature, and old-growth Douglas-fir forests in Oregon and Washington. In: Wildlife and vegetation of unmanaged Douglas-fir forests; Ruggiero LF *et al.* (eds), pp: 91-121. US Forest Service General Technical Report PNW-285.

Tappeiner JC, Huffman D, Marshall D, Spies TA, Bailey JD, 1997. Density, ages, and growth rates in old growth and young-growth forests in coastal Oregon. Can J For Res 27: 638-648. https://doi.org/10.1139/x97-015

Valkonen S, Ruuska J, Siipilehto J, 2002. Effect of retained trees on the development of young Scots pine stands in Southern Finland. For Ecol Manage 166: 277-243. https://doi.org/10.1016/S0378-1127(01)00668-5

Vanha-Majamaa I, Jalonen J, 2001. Green tree retention in Fennoscandian forestry. Scand J For Res Suppl 3: 79-90. https://doi.org/10.1080/028275801300090663

Wang M, 2005. Distributional modelling in forestry and remote sensing. PhD thesis, Univ. of Greenwich, UK, 187 pp.

WWF, 2004. Deadwood-living forests. The importance of veteran trees and deadwood to biodiversity. http://www.panda.org/europe/forests

Zenner EK, 2000. Do residual trees increase structural complexity in Pacific Northwest coniferous forests? Ecol Appl 10: 800-810. https://doi.org/10.1890/1051-0761(2000)010[0800:DRTISC]2.0.CO;2

Zenner EK, Acker SA, Emmingham WH, 1998. Growth reduction in harvest-age, coniferous forests with residual trees in the western central Cascade Range of Oregon. For Ecol Manage 102: 75-88. https://doi.org/10.1016/S0378-1127(97)00108-4