

Identifying forest structure types using National Forest Inventory Data: the case of sessile oak forest in the Cantabrian range

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Abstract

The objective of this work was the creation of a structural stand classification for sessile oak dominated forests in the Cantabrian Range (northern Spain) as a basic tool for typological inventories. A dichotomous classification system and discriminant classification equations of nine forest types were defined with an accuracy of more than 95% by evaluating the data of the second Spanish National Forest Inventory (SNFI). The presence of large old trees appears as one of the main characteristics of the Cantabrian sessile oak forests. The structure assessment method presented in this study, based on a dataset (SNFI) and free-access software, can be considered an important low-cost alternative to traditional quantitative inventory methods.

Key words: forest typology, dichotomous classification key, discriminant functions, *Quercus petraea*, silviculture.

Resumen

Identificación de tipologías estructurales con el Inventario Forestal Nacional: el caso de los robledales albares en la Cordillera Cantábrica

El objeto de este trabajo ha sido la elaboración de una clasificación tipológica para robledales cantábricos (norte de España) como herramienta base de inventario tipológico. Tomando como base de datos el inventario forestal nacional español (IFN) y con una fiabilidad superior al 95% se elaboran una clave de clasificación dicotómica y ecuaciones discriminantes de clasificación para nueve tipos estructurales de masa. La presencia de viejos robles de grandes diámetros aparece como uno de los rasgos diferenciales de los robledales cantábricos. La metodología de evaluación de la estructura forestal elaborada en el presente estudio, basada en una base de datos de libre acceso (IFN) y en un software gratuito, puede ser entendida como una alternativa de bajo coste al inventario cuantitativo tradicional.

Palabras clave: tipología forestal, clave dicotómica de clasificación, ecuaciones discriminantes, *Quercus petraea*, selvicultura.

Introduction

The first studies to establish accurate typological classification of forest structures, are based on mountain uneven-aged conifer forests in the Alps and the Jura, where the structural and seasonal heterogeneity is not clearly described by means of the classical stand descriptors such as the stand development phase or the age class (Herbert and Rebeiro, 1985; Chauvin *et al.*, 1994). In these studies, and in the numerous typologies published in central Europe afterwards (see reviews of Bruciamachie, 2001 and Gaudin and Jenner, 2001), data of traditional quantitative forest inventories are

transformed into some qualitative and quantitative variables, which are analysed through multivariate analysis to obtain a reduced number (under 20 generally) of forest structural types. The typologies are generally based on a dichotomous classification key, which facilitates the objective assessment of the forest types and each forest structure is described through the mean structural characteristics.

In the case of Pyrenean beech forests (*Fagus sylvatica* L.), Chollet and Kuss (1998), use as data source the French National Forest Inventory to establish a forest typology. Among the total number of plots with beech presence in the Pyrenees, these authors select by means of a stratified systematic inventory a sub sample of plots for which they define some quantitative and qualitative variables which are analysed and

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grouped through correspondence and hierarchical classification analyses. As a result the authors define 17 different structural types and their characteristics. Following the same methodology and using the Spanish National Inventory, Aunós *et al.* (2007) present a typology for Pyrenean fir (*Abies alba* Mill.) woods with 9 structural types depending on the diameter distribution, the vertical stratification and the species composition.

An important forest species in the Cantabrian Range is the sessile oak (*Quercus petraea* Matts. Liebl.) where the species occupies 35.385 ha (MMA-DGB, 2005a). Sessile oak reaches timberline in the area and can be classified as a mountain species (Díaz-Fernández *et al.*, 1995). Resembling most of the mountain forests in the area, the historical evolution of the sessile oak forests has gone from overexploitation into the 1970's to an almost abandonment of the forest uses at the beginning of the 21st century. At present, the self-financing capacity of silvicultural treatments is impossible in large areas, but on the contrary the carrying capacity for protected fauna of many oak forests has come to be considered a very important issue.

The objective of this work is to identify forest stand types and to develop a methodology and typology for classifying and delineating stand structures in sessile oak forests in northern Spain. Specifically we focus on: (a) linking clearly interpretable forest types with the dataset Spanish National Forest Inventory (SNFI), (b) defining the relevant structure characteristics of the different forest types, (c) assessing the best variables for the definition of forest types and (d) presenting a user-friendly forest types classification key developed upon data sets and software of free access.

Material and Methods

Study area

The study area overlaps the seed provenances areas called *Cordillera Cantábrica Meridional* (Longitude: 5° 35' W - 3° 00' W; Latitude: 43° 05' N - 42° 35' N) and *Cordillera Cantábrica Occidental* (Longitude: 7° 00' W - 5° 45' W; Latitude: 43° 05' N - 42° 30' N) (Díaz-Fernández *et al.*, 1995). Climate in these areas has characteristics of both mountain and transition areas (Atlantic and Mediterranean continental areas). Mean precipitation ranges between 800 and 1,600 mm, mean annual temperatures between 8,2°C and 10°C and a freezing period of five months. A detailed description of the study area can be found in Díaz-Fernández *et al.* (1995).

Data

The data set used in this study proceeds from the second Spanish National Forest Inventory (SNFI) (MMA-DGB, 2005b) and it has been analysed with the computer application BASIFOR (Río *et al.*, 2003). The plots of the SNFI are systematically distributed using a grid of one square kilometer. Each plot consists of four concentric subplots with radius 5, 10, 15 and 25 meters. For these subplots, the minimum diameter recorded is 7.5, 12.5, 22.5 and 42.5 cm respectively. In order to convert the data to hectares the following factors have been used 127.32, 31.83, 14.16 and 5.09 for each minimum diameter respectively. Detailed information on SNFI methods can be found in Bravo *et al.* (2003) and MMA-DGB (2005b).

Twenty stand variables were assessed in the 104 SNFI plots where *Quercus petraea* is the dominant species (sessile oak basal area and number of trees per hectare over 50% of the total plot basal area and density) (Table 1). Diameter size, tree height and potential industrial timber use were used to establish four size classes according to common market standards: Non-commercial wood (NCW: DBH between 7.5 and 17.5 cm), Timber (T: DBH between 17.6 and 32.5 cm), Saw log (SW: DBH between 32.6 and 62.5 cm) and Large saw log (LSW: DBH > 62.6 cm). For each one of these diameter classes, the percentage value of the number of trees per hectare included in each class from the total was calculated in density ($N \times \text{ha}^{-1}$: Number of trees per hectare) and in basal area ($G: \text{m}^2 \times \text{ha}^{-1}$). The vertical stratification was assessed defining four different height categories: Stratum 4 [S4: tree height (h) < 9.9 m], Stratum 3 (S3: h between 10 and 13.9 m), Stratum 2 (S2: h between 14 and 16.9 m), Stratum 1 (S1: h > 17 m). Similar to the diameter distribution evaluation, for each height class the number of trees per hectare and the basal area was calculated. The species diversity was calculated by means of the percentage density value ($N \times \text{ha}^{-1}$) and of the basal area (G) occupied by species others than the sessile oak labelled as Div(N) and Div(G) respectively.

Statistical methods

To classify the different *Quercus petraea* forest type structures, Wards' forward method with Euclidean distances was performed over the twenty variables in the 104 plots selected. The number of clusters was

Table 1. Structural variables assessed in the 104 plots in drawing up the typology

Stand variable	Abbreviation
Number of trees per hectare	N/ha
Assmann's dominant diameter (cm)	D ₀
Average quadratic diameter (cm)	D _G
Assmann's dominant height (m)	H ₀
Mean height (m)	H _M
Basal area (m ² × ha ⁻¹)	G
% of the total number of trees × ha ⁻¹ with diameter DBH ∈ (7.5 cm; 17.5 cm) (non-commercial wood)	NCW
% of the total number of trees × ha ⁻¹ with diameter DBH ∈ (17.6 cm; 32.5 cm) (timber)	T
% of the total number of trees × ha ⁻¹ with diameter DBH ∈ ((32.6 cm; 62.5 cm) (saw log)	SW
% of the total number of trees × ha ⁻¹ with diameter DBH ≥ 62.6 cm (large saw log)	LSW
% of (G) corresponding to trees with diameter DBH ∈ (7.5 cm; 17.5 cm) (non-commercial wood)	GNCW
% of (G) corresponding to trees with diameter DBH ∈ (17.6 cm; 32.5 cm) (timber)	GT
% of (G) corresponding to trees with diameter DBH ∈ (32.6 cm; 62.5 cm) (saw log)	GSW
% of (G) corresponding to trees with diameter > 62,6 cm (large saw log)	GLSW
Stratum 1: % of (G) corresponding to trees with height (h) ≥ 17 m	S1
Stratum 2.: % of (G) corresponding to trees with height (h) ∈ (14; 16.9 m)	S2
Stratum 3.: % of (G) corresponding to trees with height (h) ∈ (10; 13.9 m)	S3
Stratum 4.: % of (G) corresponding to trees with height (h) ≤ 9.9 m	S4
% of the total basal area per hectare corresponding to species others than <i>Quercus petraea</i>	Div(G)
% of the total number of trees per hectare corresponding to species others than <i>Quercus petraea</i>	Div(N)

determined according to the cut-off point of the hierarchical tree. The distance which increases sharply in the linkage distance at successive clustering steps was selected as the optimal cut-off point. Given the high values divergence of the different variables, and taking into account a certain correlation among variables which could influence the results of the Euclidean distances analysis it was decided to run the cluster analysis over the factor score matrix calculated through a previous factor analysis (extraction method: principal components) which could explain 95% of the total variance to avoid the reiterative effect caused by the variables correlation (Bisquerra, 1989). The non-parametric multiple-sample comparison of Kruskal Wallis and the median tests were run to validate the correction of the formation of the nine clusters, using as dependent variables the factorial scores and as a factor the provenance cluster.

Two different classification tools were defined to facilitate the classification of new plots or stands: a dichotomous classification key and the Fisher's classification functions. To implement the hierarchical classification key the data of the 104 plots were grouped. On each node of the decision tree the maximum variability between groups was assessed through classification tree analysis so that the partitioning according to one stand variable was optimal producing the largest improvement in goodness of fit. The split selection method was CART (Classification and regression

trees) performing «binary recursive partitioning» with style exhaustive search for univariate splits (stopping rule: stopping parameter = 0.1 fraction of object; p-level for split variable selection = 0.05; goodness of fit: Gini measure) (Breiman *et al.*, 1984).

A preliminary discriminant analysis was at first run for 90% of the plots, and the remaining ten per cent of the cases were set aside to evaluate and interpret the predictive discriminatory power. The variable inclusion process was step-by-step and the model validation in each step was made through the exact F statistic (F to enter = 3.84; F to remove = 2.71; tolerance = 0.001). Finally, a definitive discriminant analysis over the whole of the data set was run to consider all the available information and the Fisher's discriminant equations were calculated (one for each group obtained) to facilitate the plots or stands classification, either in the data set or else in new ones.

Lastly, the 9 forest types were characterized statistically with the mean and the 95% confidence intervals for the stand variables derived from the SNFI data set.

Results

Factor analysis

The value of the correlation matrix determinant was very low (<0.000) indicating high correlation between variables and appropriateness of the data for the

analysis. Ninety-five percent of the variance could be explained through nine components. The first axes were constituted by many variables related with the diameter distribution and the three first axes accumulated 61% of the variance. They can be assimilated to maturity of the stand (variables related to big old trees: 31% of the total variance), dominant height (17% of the total variance) and stands yielding saw logs (13% of the total variance). The representation quality after the factor extraction was very good, with all the communalities over 0.95. In the correlation matrix, only 1% of the residuals (differences between observed correlations in the correlation matrix and the ones estimated by the model) surpassed the 0.05 value, meaning that the goodness-of-fit of the model was acceptable.

Cluster analysis

The hierarchical tree of Ward's method depicted in Figure 1 shows that the 104 plots are categorized into

9 clusters for the distance 11. This value corresponds to a sharp increase in the linkage distances in clustering steps (between steps 96 and 98). Hence, nine clusters were determined (Table 2). Both, the hypothesis of similarity of central tendency among groups ($p < 0.00$) and the media similarity ($p < 0.05$) were rejected.

Dichotomous classification

The CART performs 18 splits and 19 nodes and the decision tree (Fig. 2) was able to classify the nine structural forest types of *Quercus petraea* with 97.2% accuracy. The overall misclassification rate was 3 misclassified cases (one case in group 5, 7 and 8 respectively).

Discriminant analysis

Nine variables out of 20 were considered in the preliminary discriminant analysis. The predictive

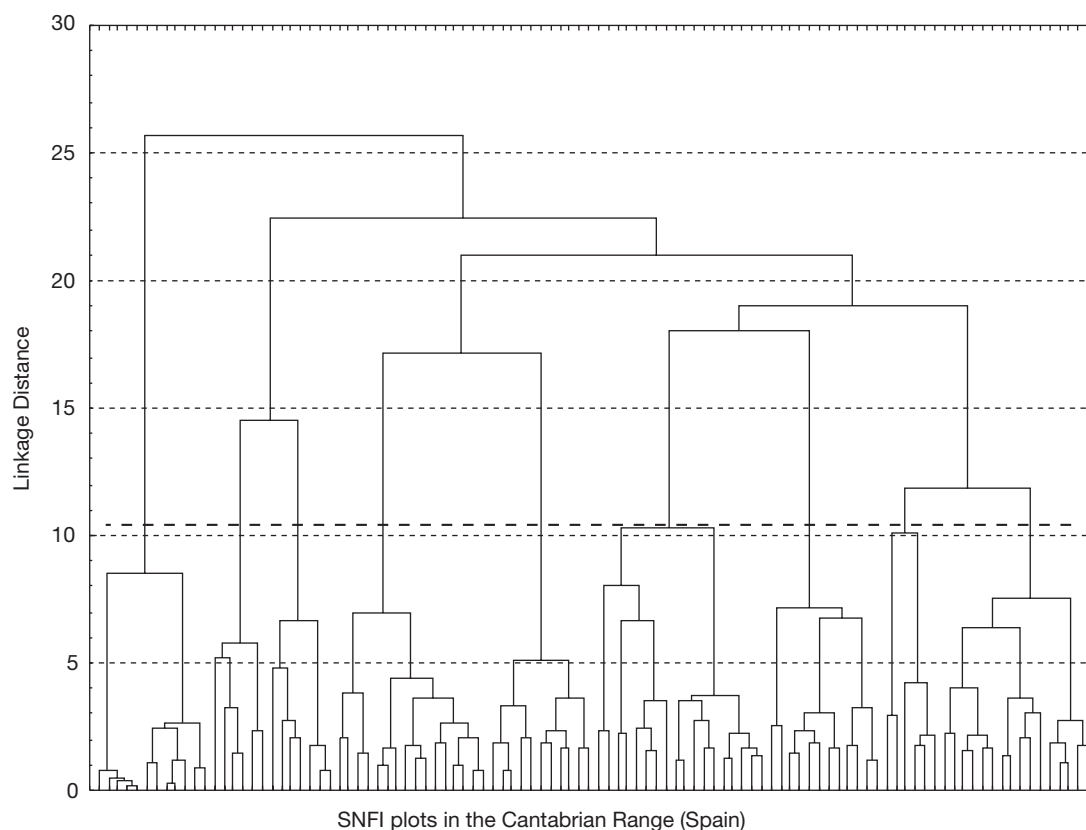


Figure 1. Cluster analysis. Hierarchical tree diagram for 104 sessile oak dominated SNFI plots in the Cantabrian Range (Ward's method with Euclidean distances). The discontinuous horizontal line through the dendrogram intersects the vertical cluster lines defining the nine typologic groups.

Table 2. List of the nine forest types and mean and 95% confidence intervals (in brackets) of the main forest structure variables. Acronyms in Table 1

Structure type	Variables				
	N/ha	Dg (cm)	G (m ² /ha)	V (m ³ /ha)	H ₀ (m)
1. Multilayered structure, young	497 (311; 684)	27 (23; 30)	23 (17; 29)	116 (73; 160)	12 (10; 15)
2. Uniform timber trees structure	434 (241; 627)	38 (26; 50)	32 (26; 39)	193 (151; 235)	19 (17; 21)
3. Multilayered structure, old	640 (416; 863)	25 (22; 29)	27 (20; 33)	137 (92; 182)	13 (11; 15)
4. Silvopastoral structure, open (Dg > 50 cm)	42 (8; 74)	53 (46; 61)	10 (2; 18)	41 (2; 80)	11 (7; 14)
5. Uniform pole wood structure	786 (523; 1,050)	15 (13; 17)	13 (9; 17)	43 (28; 57)	8 (7; 8)
6. Silvopastoral structure, open (Dg > 75 cm)	22 (9; 35)	78 (66; 92)	10 (4; 16)	39 (12; 67)	13 (10; 16)
7. Silvopastoral structure, with area wide regeneration	1,215 (573; 1,857)	29 (18; 40)	82 (64; 99)	376 (328; 424)	13,2 (11; 15)
8. Silvopastoral structure, open (Dg < 35 cm)	140 (28; 251)	29 (24; 34)	10 (1; 20)	35 (2; 72)	9 (6; 11)
9. Two layered structure	1,306 (991; 1,262)	19 (16; 21)	32 (27; 36)	146 (123; 169)	12 (11,3; 13)

discriminatory power was high with 87.5% accuracy (94.8% in the cross-validation). Among the groups selected in the analysis, six groups were correctly classified in 100% of the cases, two were correctly in classified over 90% of the cases and only one group was correctly classified in 75% of the cases. All the hierarchical correlation coefficient values were high and the λ of Wilks values and the level of significance for the entire set of variables was zero in all cases. This means the information contained in each function was statistically significant and we concluded that the functions divide the different groups. The high statistical significance of the models obtained and the high number of correct classifications indicated that the data set and equations would give good results in the prediction of the provenance cluster of each plot. Thus, to develop definitive discriminant analysis and the Fisher classification equations, ten variables were considered for all of the plots ($n = 104$) (Table 3). The performance of the model fit was very high with a 96.2% correct classification in the cross-validation. The classification functions yielded 100% correct classifications for all classes but three (2, 3 and 5). The correct classification of groups 3 and 5 was over 90%. Group number 2 was correctly classified in 83.3% of the occasions and the misclassifications were concentrated in a contiguous typology class.

Discussion and Conclusions

A classification of structure types and a system for the identification of discrete types has been efficiently developed by using data from the Spanish National Inventory and multivariate analysis. The typology and

classification tools should be considered as an analytic and descriptive element for sessile oak forests. Its main application scope is based on the qualitative inventory and on the stratification, looking toward a common terminology and descriptive process at the stand level (Bruciamachie, 2001). The fact that the costly tasks of measurement, typical in quantitative inventories, are not necessary in the stand type characterization means it can be performed at low cost. Because the typology is completed with the group descriptive files presenting the average stand descriptors (Table 2), the forest type characterization can replace the traditional quantitative inventory when the accurate estimation of stocks is not an important variable for management like, for example, wildlife habitat selection studies, forest risks prevention programmes (wildfire, avalanche release, etc.), researches of forest dynamics or in the assessment of different forest functions in space and time.

Assessment of forest stand structures and Spanish National Inventory (SNFI)

Large-scale inventories, as the national forest inventories, permit to obtain in a precise way a very representative sample of the diversity present in a large territory such as the Cantabrian Range. The main limitation is the wide systematic grid (1 km²) used in this type of inventories that may exclude forest stands with remarkable interest. This fact could be important in forest species with a very fragmented distribution as *Quercus petraea* in the Cantabrian Range (García *et al.*, 2005).

Another problem detected in the use of the SNFI is the minimum tally diameter (7.5 cm). For sessile oak

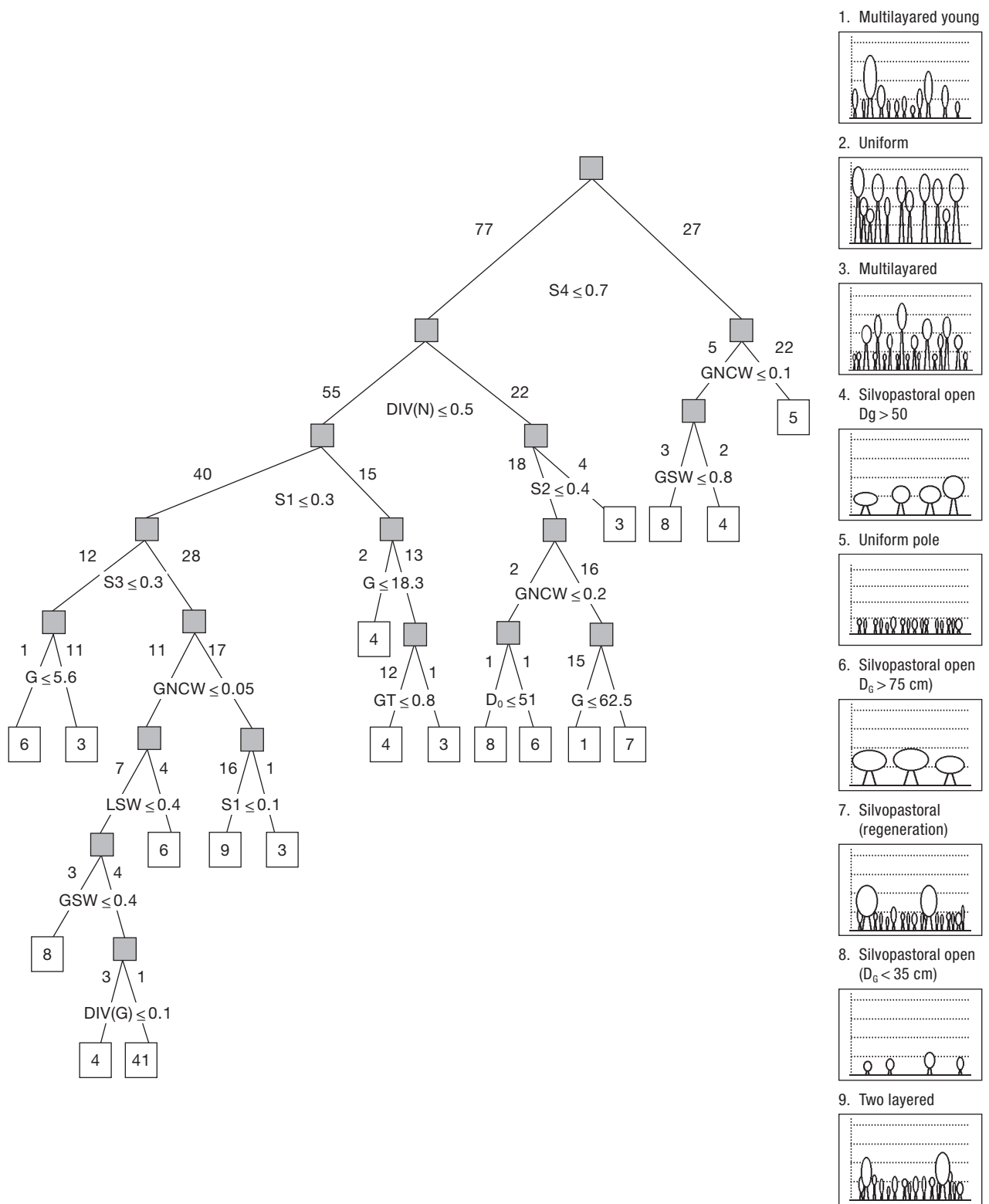


Figure 2. Dichotomous classification key and typology of sessile oak dominated forests (sessile oak basal area over 50% of the total stand basal area) in the Spanish National Inventory Plots of the Cantabrian Range (northern Spain). The variable below each node describes the split condition. The values printed above the nodes indicate the number of cases (SNFI plots) sent to each of the new (child) nodes from their root (parent) node. Acromyms in Table 1.

Table 3. Discriminant coefficients of Fisher classification functions (Ward method) of the nine *Quercus petraea* forest types in the Cantabrian Range. Acronyms in Table 1

Group	1	2	3	4	5	6	7	8	9
D ₀	1.19	1.37	0.97	1.52	1.29	1.37	1.92	1.30	1.29
G	-0.12	-0.17	-0.01	-0.51	-0.13	-0.46	0.23	-0.35	0.02
DIV(N)	2369	-14191	-6859	-23326	-20415	-12515	-6237	-7794	-18163
NCW	46.09	44.76	39.60	52.81	52.83	39.44	65.87	18.15	55.12
SW	-0.22	14.92	7.49	120.06	5.37	40.60	9.48	-12.70	13.78
LSW	-41.92	-45.88	-33.54	-45.58	-48.02	16.98	-79.99	-62.22	-50.81
GSW	-0.63	-18.82	-7.53	-47.51	-20.36	-20.48	-25.66	-20.25	-21.22
S4	56.60	62.27	35.94	46.73	76.92	45.64	65.70	72.11	66.48
S3	66.45	67.16	41.27	56.32	69.35	52.49	74.92	66.63	77.72
S1	77.72	96.01	47.14	63.40	85.14	54.64	79.16	77.80	81.69
(Constant)	-67.15	-71.25	-35.77	-93.93	-74.52	-78.23	-138.28	-53.15	-77.18

Wilk's Lambda = 0.00011; aprox. F (80.554) = 22.1925; p < 0.0000.

forests with asexual resprouting, to consider a minimum diameter class of 10 cm, could lead to the exclusion of inventory and assessment stands of young coppice forests. The data sources SNFI with observational information on small trees facilitate qualitative (not quantitative) studies on the resprouting through ordinal variables. However, the strong influence of external factors such as herbivore predation on resprouting, as well as the ordinal character of these SNFI variables, recommended not using resprout for the establishment of the forest typology. And it can also be mentioned that the younger trees are only considered in a small area (due to the concentric sampling system) which can imply estimates of poor accuracy. This factor can be extremely important in heterogeneous stands or for frequent resprouting in an aggregated way.

Typological classification of sessile oak dominated forests

The discernability of the forest structure type was very good. The main reason for this is probably the above mentioned sampling intensity and source of information and data supply of the SNFI. Main advantage of the typology presented in this study is that it is based on a dataset and software of free access (Río *et al.*, 2003; MMA-DGB, 2005a,b). One other important advantage is that the typology is easy to assess. A typological classification using only cluster analysis would not permit this. Overall, the performance of the CART-decision tree and the discriminant models to classify the data is noteworthy (cross-validation classification accuracy $\geq 90\%$, predictive discriminatory accuracy

87.5%). Although the predictive values are very high it has to be pointed out however that both the plots used for the establishment of the typology and the plots set aside for evaluation come from the same data set (SNFI). In this paper we do not test the quality of the classification among different assessors. Even so, the practical application of the typology in the study area indicates that the misclassification is very low among foresters trained in relascope inventory tasks.

Concerning the methodology for the analysis of diameter distribution, there is an important difference between typologies published in Europe for broadleaved forests and the present study. While Aubury *et al.* (1990) in studying sessile oak and Chollet and Kuus (1998) for beech, used three different diameter ranks, in the present study four different diameter types were considered with the larger diameters (> 62,6 cm) added to the other three. The same difference is found for the typologies published in Europe for conifers (Herbert and Reboiro, 1985; Chauvin *et al.*, 1994; Chollet *et al.*, 2000; Aunós *et al.*, 2007). The addition in the present work of this other diameter class to include the frequent existence in the Cantabrian oak sessile forests of big trees was highly significant in the multivariate analysis. The first factorial axis, with 31% of the variance explained, is strongly saturated with variables related to trees yielding large saw logs. Thus, the frequent presence of big old trees can be seen as an outstanding characteristic of high conservational value of the Cantabrian sessile oak forests.

The data sources used in the assessment of the typology imply a uniform and systematic representation of the seasonal, propriety, exploitation method and silvicultural history variability within the Cantabrian

Mountains. This fact implies a double consequence. First, within its application range, the typology permits the analysis of very heterogeneous types among all the possibilities in sessile oak forests. On the other hand, the broad systematic grid used in the creation of the typology (1 plot per 100 ha) implies that it should not be taken as a stationary and fixed method. In fact, in the application of this typology to a forest stand or reduced group of forests, it is possible and predictable that new forest types will appear. These new groups can be included and described, to adapt the typological classification for that territory. As stated before, the accuracy of the classification and its practical application will strongly depend on forester's skills and experience.

The structure assessment method based on the dataset of the national forest inventories has been applied successfully in characterizing sessile oak-dominated forests in the Cantabrian Range, but it would have to be adapted in order to identify structures in other forest communities. The number and type of variables used in the present study have not to be seen as fixed for further typologies. For example, the inclusion in the present study of variables considering the presence of big old trees like ancient pollards could not be necessary in forest without silvopastoral heritage. Forest typologies with the underlying classification tools (binary key and discriminant functions) allow foresters to describe in an objective manner forest conditions and to make a precise analysis of forest stands with low costs in relation to traditional inventories. They are likely to be more widely used in the future in Spanish silviculture as decision-making management tools for planning forest interventions in forests where the precise estimations of stocks is not necessary.

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