A long-scale biodiversity monitoring methodology for Spanish national forest inventory. Application to Álava region

Iciar Alberdi[1]*, Isabel Cañellas[1] and Sonia Condes[2]

[1] INIA-CIFOR. Departamento de Selvicultura y Gestión de los Sistemas Forestales. Ctra. A Coruña, km 7,5. 28040 Madrid, Spain. [2] Escuela Técnica Superior de Ingenieros de Montes. Universidad Politécnica de Madrid. Ciudad Universitaria, s/n. 28040 Madrid, Spain

Abstract

Aim of study: In this study, a methodology has been designed to assess biodiversity in the frame of the Spanish National Forest Inventory with the aim of evaluating the conservation status of Spanish forests and their future evolution. This methodology takes into account the different national and international initiatives together with the different types and characteristics of forests in Spain.

Area of study: Álava province (Basque country, Spain).

Material and methods: To analyse the contribution of each of the different indices to the biodiversity assessment, a statistical analysis using PCA multivariate techniques was performed for structure, composition and dead wood indicators.

Main results: The selected biodiversity indicators (based on field measurements) are presented along with an analysis of the results from four representative forest types in Álava by way of an example of the potential of this methodology.

Research highlights: The statistical analysis revealed the important information contribution of Mingling index to the composition indicators. Regarding the structure indicators, it is remarkable the interest of using standard deviations and skewness of height and diameter as indicators. Finally it is interesting to point out the interest of assessing dead saplings since they provide additional information and their volume is a particularly useful parameter for analyzing the success of regeneration.

Key words: species richness; structural diversity; dead wood; NFI; PCA.

Introduction

The availability of appropriate forest information is essential to the decision making process undertaken by forest managers and policy makers. This information must reflect the biological significance of the forests in a broad context so that global biodiversity is not inadvertently compromised due to inappropriate forest management (Noss, 1999). In order to assess forest condition, a number of pertinent measurable indicators are required. Quantifying biological diversity is an important objective in the assessment of non-timber resources in forest surveys (Groombridge and Jenkins, 1996).

National Forest Inventories (NFIs) are generally based on traditional methodology and protocols differ from one country to another. Due to the fact that they were originally designed to estimate species distribution and timber stocks, no pre-established methodologies exist for analysing forest biodiversity. Moreover, there is a lack of agreement as regards the most suitable biodiversity indicators. However, much effort has been focused on biodiversity protocols, such as FOREST BIOTA; EMAN (Roberts-Pichette and Gillespie, 1999) or BIOCONDITION (Eyre, 2011). Furthermore, European countries are required to comply with a number of international requirements such as those included in the FAO Global Forest Resources Assessment and

Abbreviations used: NFI (National Forest Inventory); PCA (Principal Components Analysis); IAP (Index of Atmospheric Purity); IVI (Importance Value Index).

the Ministerial Conference on the Protection of Forests in Europe (Forest Europe), along with those defined in other International Conventions regarding requirements for national information such as United Nations Framework Convention on Climate Change and Kyoto Protocol, which are also of importance in relation to NFIs. Cross-regional scale analyses rely heavily on the information provided by NFIs due to the large number of plots and variables which they record (Alberdi *et al*., 2010a). Therefore, many countries are increasing the number of variables recorded in their NFI, establishing a "multi-functional" tool, capable of providing all the required information.

Each country must develop a methodology which allows all the required information to be obtained, taking into account their respective NFI designs, logistics and vegetation communities. Most countries have already developed national biodiversity strategies; those developed in Spain being the Spanish Forest Strategy (Ministerio de Medio Ambiente, 2000) and the Spanish Inventory of Natural Heritage and Biodiversity (Law 556/2011).

As previously mentioned, the NFIs must be harmonized so that the information provided in each country is consistent. In recent years, a number of initiatives have been undertaken such as Action Cost E43 (Lanz *et al*., 2010), FUTMON (Ferretti, 2010a) or the Action Cost USEWOOD. However, despite these initiatives, prospects for standardizing inventories are minimal (McRoberts *et al*., 2009, in Ferretti, 2010a), although a moderate level of Europe-wide harmonization is considered possible depending on the objective (Winter *et al*., 2008, in Ferretti, 2010b).

A summary of the Spanish National Forest Inventory (NFI) is presented in Table 1 (Alberdi *et al*., 2010b). The assessment units are the provinces (50 in Spain) which have a mean surface of one million ha. In the Third NFI each year, five provinces were sampled using the same field protocol. From the second cycle onwards, the plots are permanent, enabling growth comparisons to be undertaken. Sample plots were established at the intersections of a 1-km × 1-km UTM grid. Permanent field plots consist of four concentric circular fixed areas with radii of 5, 10, 15 and 25 m.

To satisfy the new information and management requirements, a number of biodiversity indicators were assessed using the data provided in the Spanish NFI. As more detailed, specific information was required, a decision was taken to design an appropriate methodology for estimating biodiversity within the framework of the NFI, additional to the existing inventory field data. This methodology, adapted to the Spanish NFI, has been developed by taking into consideration the national forest characteristics along with the International requirements and new initiatives (Alberdi *et al*., 2012) and it has been implemented since 2004 (Third Spanish NFI).

The aim of this paper is to describe the methodology designed to estimate forest biodiversity within the framework of the Spanish NFI. The indices calculated to assess biodiversity are based on the additional field measurements as well as on the conventional NFI variables. As an example of how the methodology is applied, the results from four indicative forest types in the province of Álava (Basque country) are presented. A statistical study using a Principal Component Analysis (PCA) is carried out on the estimated biodiversity indicators in order to analyze the correlation between them and to identify the most suitable indicators to evaluate the main variables defining forest biodiversity.

Material and methods

Biodiversity assessment. Selected variables, indicators and methodology

The assessment of biodiversity for Spanish forest was conducted following the national features classification system (Alberdi *et al*., 2012) applied for the different forest types:
i)   Ground cover.
ii)   Tree and shrub species composition.

Table 1. Details of the National Forest Inventories developed in Spain

Inventory	Years	Stratification	Sampling method and field plots	Number of plots
NFI1	1965-1974	Grid over photographs	Optimal allocation of plots; temporary plots	65,000
NFI2	1986-1995	Grid over maps	Systematic 1-km × 1-km grid; permanent plots	84,203
NFI3	1997-2007	Grid over digital maps. 1:50,000	Same systematic grid as NFI2; permanent plots	95,327
NFI4	2008-2018	Grid over digital maps 1:25,000	Same systematic grid as NFI2; permanent plots	Not available

Table 2. Average ground cover percentages values for the four forest types studied in the province of Álava

Forets types	Monterey pine plantation	Scots pine forest	Beech forest	Mixed forest
Bare soil	2.48	4.21	2.80	5.44
Stones	1.03	2.54	3.37	7.31
Bedrock	0.13	1.25	4.72	2.67
Organic matter	43.38	23.12	56.87	22.92
Liquen and moss cover	2.03	9.96	6.93	7.30
Fern cover	11.09	5.51	4.21	2.10
Herbaceous plant cover	9.53	38.36	12.44	32.80
Shrub basal area cover	29.68	14.76	7.66	19.19
Peat bog	0.31	0.03	0.20	0.00
Waterlogged	0.13	0.00	0.27	0.15
Water course	0.00	0.00	0.28	0.00
Tree basal area	0.21	0.26	0.25	0.12
Average value of Shannon-Weaver index	1.08	1.33	1.06	1.36
Deviation of Shannon-Weaver index	0.29	0.25	0.42	0.26

iii) Forest structure.
iv) Dead wood.
v) Herb and fern richness.
vi) Flora conservation: threatened species.
vii) Epiphytic lichens.

Biodiversity analyses are based on the classification of the forest types in each province. In Spain, there is a national classification based on dominant species, dominant species crown cover and species age classes.

Ground cover

The term ground cover refers to the cover by plants, litter, rocks, etc in a vegetation type (Bonham, 1989). Ground cover estimations are based on new field monitoring data. Estimations are made in the NFI 25 m radius plot. Measurements of the percentage of the sampling units covered by different types of ground cover (Table 2) are recorded. Many indicators can be derived from field cover estimation such as average cover; number of plots with more than 75% of one specific component or the Shannon-Weaver index (Shannon and Weaver, 1948) among others (Table 3).

Tree and shrub species composition

These variables are routinely recorded for the selected trees in the NFI's. Some of the indicators calculated are shown in Table 4. Rényi's diversity ordering method (Rényi 1961) is also calculated using the statistical program "*Species Diversity and Richness*" (Seaby and Henderson, 2006) to avoid inconsistencies result of summarising both relative abundance and species number using a single number (Patil and Taillie, 1979); therefore, the use of a diversity index family is required such as Rényi's family.

The Mingling index (Table 4) is the only one which requires additional data, specifically, the species of

Table 3. Average and deviation of Shannon-Weaver index for the four forest types studied in the province of Álava

Forets types	Monterey pine plantation	Scots pine forest	Beech forest	Mixed forest
Average value of Shannon-Weaver index	1.08	1.33	1.06	1.36
Deviation of Shannon-Weaver index	0.29	0.25	0.42	0.26

Table 4. Some of the indices used to assess forest biodiversity

Indices	Core variable		Formula	Variables
Shannon-Weaver (Shannon and Weaver 1948)	Species composition	[1]	$H = \sum_{i}^{S} (-\ln p_i) p_i$	S: species number; p_i: proportion of the i specie referred to the total individuals
Margalef (Clifford and Stephenson 1975 modified by Margalef 1998)	Species composition	[2]	$D_{MG} = \dfrac{S-1}{\ln N}$	S: species number; N: individual number
Berger-Parker (Berger and Parker 1970)	Species composition	[4]	$1 - D_{BP} = 1 - \dfrac{N_{max}}{N}$	N_{max}: individual number of the most represented species; N: total individual number
Simpson (Simpson 1949; modified by Magurran 1988)	Species composition	[5]	$1 - D = 1 - \sum \left(\dfrac{n_i(n_i-1)}{N(N-1)} \right)$	n_i: individual number of the i species; N: total individual number
Rényi's diversity index family (Rényi 1961)	Species composition	[6]	$H_\alpha = \dfrac{\left(\log \sum_{i=1}^{s} p_i^{\alpha} \right)}{(1-\alpha)}$	α: order ($\alpha \geq 0$); p_i: proportional abundance of the ith species.
Mingling index (M) (Gadow and Füldner, 1995)	Species composition	[7]	$M_i = \dfrac{1}{3} \sum_{j=1}^{3} v_{ij}$	Where i and j: individual trees that will be compared; v: 1 if i and j are the same species; 0 if not
Clark and Evans index (I_{CE})	Horizontal tree structure indices	[8]	$I_{CE} = \dfrac{\frac{1}{n} \sum_{i=1}^{n} D}{0.5\sqrt{10000/N}}$	D_{tt}: distance between tree i randomly selected and its nearest neighbour; N: number of trees per ha
Gadow's uniform angle index	Horizontal tree structure indices	[9]	$W_i = \dfrac{1}{4} \sum_{1}^{4} w_j$	w_j: 1 if $\alpha \geq 100°$; 0 if $\alpha > 100°$; α is the angle between trees (see Fig. 4). Four measurements per plot
Standard deviation of tree height	Vertical tree structure indices	[10]	$s = \sqrt{\dfrac{\sum_{i=1}^{n}(h_i - \bar{h})^2}{n-1}}$	h_i: tree height; $\bar{h}$: average height
Species profile index (Pretzsch 1996)	Vertical tree structure indices	[11]	$A = -\sum_{i=1}^{S} \sum_{j=1}^{B} \begin{cases} p_{ij} \cdot \ln p_{ij} & p_{ij} > 0 \\ 0 \end{cases}$ $p_{ij} = \dfrac{n_{ij}}{n}$	Band 1: 100-80% of maximal tree height (h_{max}); Band 2: 80-50% of h_{max}; Band 3: 50-0% of h_{max}; n_{ij} = number of trees of species i in height band j; n = total number of trees; S = number of species; B = number of height bands = 3

neighbouring trees. Thus, the location of each species must be known. However, in the Spanish NFI, not all the trees are measured in the concentric plots. Therefore, additional spatial information must be recorded in inventories, as shown in Fig. 1.

$$H_\alpha = \frac{\left(\log \sum_{i=1}^{s} p_i^{\alpha} \right)}{(1-\alpha)} \qquad [1]$$

Stand structure

The indices for the horizontal stand structure of the tree layer are the following (Table 4): ratio of conifers/broadleaves (by occupied area, basal area and number of trees); standard deviation of tree diameter; diameter skewness; Clark and Evans index (Clark and Evans, 1954); Gadow's uniform angle index (Gadow, 1993); number and distribution of mature trees.
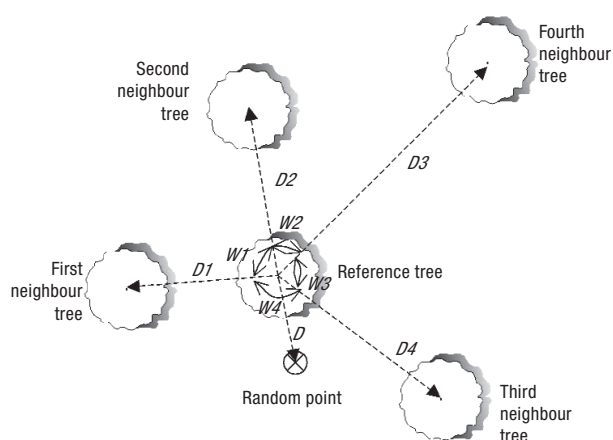
Figure 1. Representation of the additional structure variables measured to complement the recorded information in the Spanish National Forest Inventory. D_i: Distance i neighbour tree-Reference tree. W_i: Angle i neighbour tree- $i+1$ neighbour tree. $i = 1$-4.

Table 5. Vertical complexity index classes defined to evaluate the combined horizontal and vertical tree and shrub stand structure indices

Class	Shrub cover (Sc)	Number of tree layers Tree crown cover (Cc)
10	Sc ≥ 40	2 layers or more
9	0 ≤ Sc < 40	2 layers or more
8	Sc ≥ 70	1 layer; Cc ≥ 50
7	40 ≤ Sc < 70	1 layer; Cc ≥ 50
6	10 ≤ Sc < 40	1 layer; Cc ≥ 50
5	Sc < 10	1 layer; Cc ≥ 50
4	Sc ≥ 70	1 layer; Cc < 50
3	40 ≤ Sc < 70	1 layer; Cc < 50
2	10 ≤ Sc < 40	1 layer; Cc < 50
1	Sc < 10	1 layer; Cc < 50

Additional monitored field measurements to assess neighbour indexes are shown in Fig. 1.

The indices for the horizontal shrub structure are based on the values for species crown cover in the NFI 10 m radius subplot. The indicator selected is the percentage of plots covered by shrubs, with the following crown cover classes: from 0 to 9%; from 10 to 39%; from 40 to 69%; and above or equal to 70%. The percentage of plots with crown cover greater than 100% (due to species crown cover overlaps) is also indicated.

Vertical indicators are based on height measurements that are taken in the NFI's. The indicators considered for vertical stand structure in the tree layer are the following (Table 4): percentage of one layered or multilayered plots; percentage of even-aged, two-aged or uneven-aged stand plots; dominant tree height (Assman, 1970); average tree height; standard deviation of tree height and species profile index (Pretzsch, 1996).

Three indices which consider the horizontal and vertical stand structure are calculated: tree importance value index (IVI) (Curtis and MacIntosh, 1951); importance value index for shrubs (Gordillo *et al*., 2000) and vertical complexity index (Gordillo *et al*., 2000).

The IVI, in the case of trees, is calculated as the sum of the relative presence, the relative density, and the relative basal area while the IVI for shrubs is calculated as the sum of relative presence, the relative crown cover and the pseudo-volume (by multiplying the crown cover by the average height per species recorded in each plot).

The vertical complexity index combines information on both tree and shrub structure, which is divided into ten classes. The variables included in this index are: the number of tree layers, the tree crown cover and the shrub cover. The vertical complexity index classes' definitions are shown in Table 5.

Other information relative to structure is derived from the traditional NFI data, such as the stage of the stand in which the plot is located (even-aged, two-aged, uneven-aged).

Dead wood

In the Spanish NFI, only standing dead wood was recorded in order to estimate tree growth. Therefore, additional measurements to assess dead wood were needed. Dead wood data is recorded in the NFI 15 m radius subplot. The dead wood components considered are those listed in the ForestBiota project (Travaglini and Chirici, 2006) although certain adaptions were necessary. These components are as follows: dead standing trees (including snags, dbh > 7.5 cm, height > 1.3 m); dead downed trees (dbh > 7.5 cm); dead standing and downed saplings (2.5 < dbh < 7.5 cm); downed coarse wood pieces/downed branches (diameter at the thinner > 7.5 cm, length > 30 cm); stumps/snags (diameter at mid height > 7.5 cm, total height < 1.3 m); coppice stumps (representative diameter at mid height > 7.5 cm, total height < 1.3 m); and accumulation (diameter > 7.5 cm of a representative branch at half length).

Tree as well as shrub species are recorded and the five decay classes proposed by Hunter (1990) and Guby

and Dobbertin (1996) are considered, although two additional classes are defined: hollow dead wood (to avoid overestimation of volume) and recently cut (so that the probable amount of deadwood removed can be deduced).

The five decay classes definition adopted by the Spanish NFI are the followings: (1) Bark intact, small branches present, wood texture intact; (2) Bark intact, no twigs; (3) Trace of bark, no twigs, wood hard, texture with large pieces; (4) No bark, no twigs, wood soft, texture with blocky pieces; (5) No bark present, no twigs, wood soft and powdery texture.

Downed trees and saplings are recorded when the stump or thickest end is within the plot. Other dead wood components are recorded when more than 50% of the piece is inside the plot. Stumps are recorded regardless of whether they are the result of human intervention or natural causes.

To estimate tree volume (either standing or downed) NFI stem and branch equations are used, considering the dendrometric variables, species and tree shape (MMA, 1990; MARM, 2008). The volume of dead standing and downed saplings is calculated assuming conical form; the volume of downed branches is calculated using Smalian's formula (Smalian, 1837) and the stump and accumulations volume are calculated using Huber's formula (Loetsch et al., 1973).

Herbaceous plant and fern richness

The number of herbaceous species belonging to *Poaceae,* those not belonging to *Poaceae* and fern is recorded as part of the biodiversity measurements although the species *taxa* are not identified. A quadrant subplot with a radius of 5 m and a north-easterly orientation is established in the centre of the NFI plot. It is important to take into account when evaluating this information that the Spanish NFI is undertaken throughout the whole year. Therefore, for the purposes of comparison between areas, the time of year in which the data was recorded must be considered. The percentage of plots of each forest type with 1, 2, 3, etc. different species is calculated as an index.

Flora conservation: threatened species

A list of threatened species to be monitored is elaborated for each province, taking into account both National and Regional sources of information. Presence

and number are recorded in the 25 m circular plot. The species lists tend to comprise mainly woody species because of their perennial nature, and the fact that they can be easily identified by teams in the field.

The results are presented according to the level of threat.

Epiphytic lichens

A modified version of the methodology proposed by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, operating under the UNECE Convention on Long-range Transboundary Air Pollution for Level II plots (Stofer et al., 2003) was adopted by the Spanish NFI for biodiversity assessment. Monitoring of epiphytic lichens is carried out on five randomly selected living trees in the NFI plot. The lichen inventory must be undertaken for all the tree species present in the plot, taking into consideration the proportion of each species. The number of individuals of the three lichen morphological groups must be identified: crustaceous, foliaceous and fruticose. The lichen indicators selected are the following: average number of different *taxa* identified per tree, species of each morphological group; Shannon-Weaver index considering the coverage of each species present; Index of Atmospheric Purity (IAP) (Amman et al., 1987) per tree species and per forest type. The IAP is obtained by the sum of the lichen presence frequency.

Data to which the methodology is applied

As an example of the application of the methodology, some of the results obtained in the province of Alava (Basque country) to assess forest biodiversity are presented for four indicative forest types (Table 2). Alava province is situated in the North of Spain. Two of the three bio-geographical regions in peninsular Spain (*i.e.* Mediterranean and Atlantic) are well represented and therefore there is a rich diversity of ecosystems within this region. Alava province has 189,132 ha of forested land in which 1,374 plots were surveyed in the NFI-3. In 1,303 of these plots, an additional biodiversity inventory was undertaken.

Four forest types were selected as examples of how the results obtained through the application of the methodology to NFI's are used in the evaluation of

biodiversity: two conifer pine forests, Monterey plantation pine forest (*Pinus radiata* D. Don) and Scots pine forest (*Pinus sylvestris* L.); a broadleaved beech forest (*Fagus sylvatica* L.) and a Mediterranean mixed forest of conifers and broadleaved trees. The numbers of analyzed plots were 128, 121, 231 and 101 respectively with forest areas of 13,610 ha, 13,447 ha, 25,073 ha and 8,986 ha. This variety of forest types allows interesting comparisons to be made.

Statistical analysis

Additionally, a statistical analysis including all the plots (1,303) in the province of Álava was undertaken with the aim of determining the relative importance of each indicator and the relationships among them. Correlation analysis (with Spearman correlation coefficient) was used as well as Principal Component Analysis (PCA) multivariate techniques (Jolliffe, 2002) using Statgraphics 5.0 and SPSS 13.0. The rotation method Varimax with Kaiser normalization has been applied. The PCA results will allow decision making in order to select certain indicators as some of them will be highly correlated, others will show an unexpected independence and their relative importance will be reflected in the analysis. The groups analyzed were: 1) tree and shrub species composition; 2) forest structure (horizontal and vertical structure); 3) dead wood.

Results

## Application of the methodology to four indicative forest types in the province of Álava

Ground cover

Ground cover information is compiled both from the traditional NFI inventory (tree basal area only) and from the additional biodiversity information. According to the Shannon-Weaver index, the mixed forest and the Scots pine forest are the more complex forest types as regards ground cover (Table 3). The highest values for litter are found in the beech forest while the lowest ones are found in the mixed forest (Table 2). Atlantic beech forests are shady and have a high level of humidity. They are characterized by high percentages of fallen leaves and low presence of other species.

In the more Mediterranean type forests, however, such as the mixed forest or Scots pine forest, the crowns are more open, allowing the sunlight to reach the ground and therefore facilitating the presence of higher percentages of herbaceous plants. The high percentage of bare soil in the Mediterranean mixed forest indicates a greater probability of erosion.

Tree and shrub species composition

Beech forest accounts for the greatest percentage of forested area and presents the highest total number of tree species. However, other composition indicators reveal that this high value is due to the large area covered by this forest type. If other indices are taken into account, such as the average number of species per plot, the ranking changes completely, with the mixed forest and Scots pine forest being those which display the greatest diversity of species (Figs. 2 and 3). Scots pine forests are more open, which leads to high floristic biodiversity as well as a notable presence of broadleaved species such as oaks (*Quercus pyrenaica* Willd*., Q. faginea* Lam. and *Q. robur* L.), maples, chestnuts and *Juniper* trees. Mixed Mediterranean forests in this area are composed mainly of semideciduous Mediterranean species along with a scattering of Atlantic species. Different species of oak such as *Quercus pyrenaica, Q. faginea* or *Quercus ilex* L. occur alongside *Quercus robur* o *Tilia* spp. Conversely, the Monterey pine plantation and the beech forest display the lowest species diversity. Neither of these forest types allows much light to penetrate the canopy, which is why other light demanding woody species are unable to thrive in them.
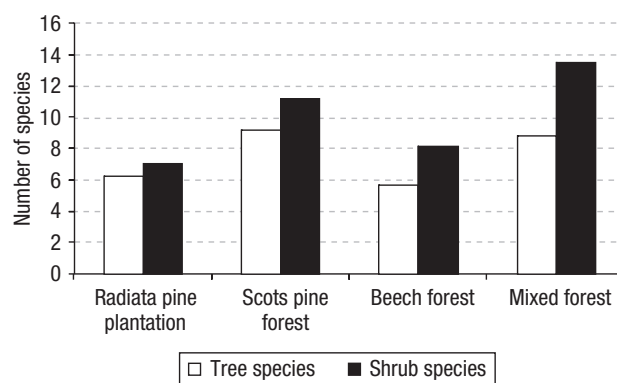
Figure 2. Average number of tree and shrub species per plot and forest type in the province of Álava (Basque country).
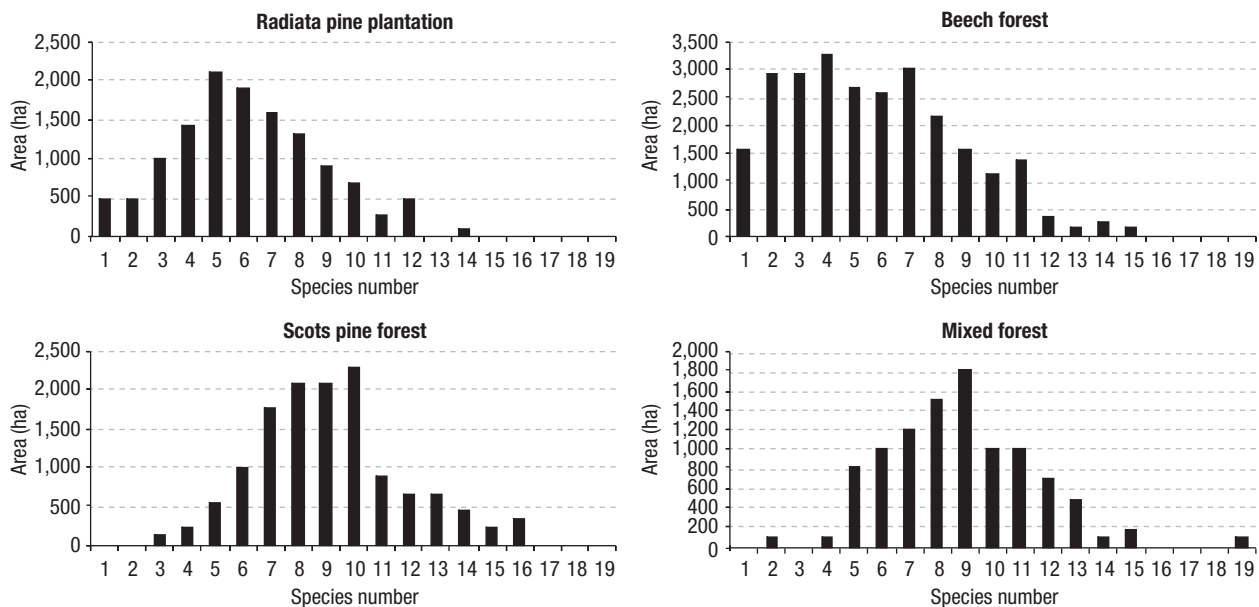
Figure 3. Histogram showing the number of species present in the four forest types considered in the province of Alava (Basque country) in relation to the area occupied by them.

Stand structure

A number of significant forest structure indicator values for the selected forest types are shown in Tables 6 and 7. The standard deviation of tree diameter reveals higher horizontal structure diversity in the beech forest. Spatial distribution can be determined using the Clark and Evans Index for example. As expected, the Monterey pine plantations displayed a regular distri-

Table 6. Averages of some stand structure indicators and their respective standard deviation for the four forest types considered in Álava province (Basque Country)

	Monterey pine plantation	Scots pine	Beech forest	Mixed forest
Horizontal stand structure indicator				
Sd	72.97	74.80	114.97	56.63
S(Sd)	54.01	25.96	50.36	36.89
I_{CE}	1.47	1.29	1.12	1.08
$S(I_{CE})$	0.76	0.61	0.90	0.74
Vertical structure indicator				
A	0.71	0.95	0.94	1.04
S(A)	0.37	0.38	0.36	0.48

Sd: standard deviation of tree diameter. S(Sd): standard deviation of Sd. I_{CE}: Clark and Evans index. $S(I_{CE})$: standard deviation of I_{CE}. A: species profile index. S(A): standard deviation of A.
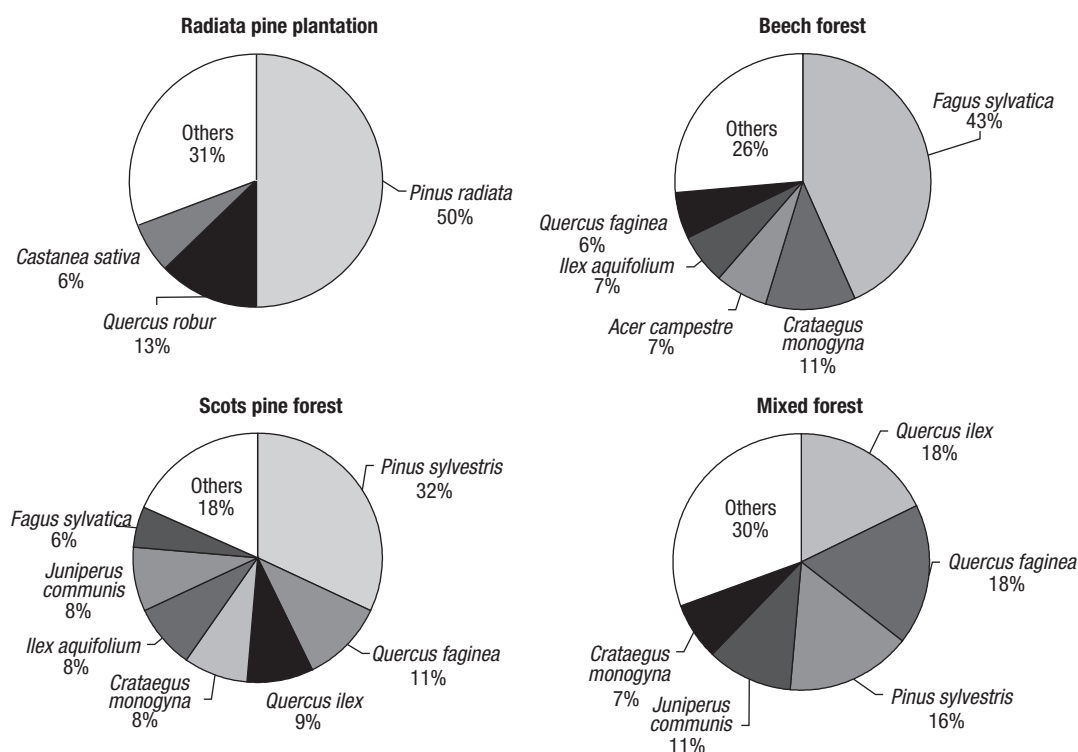
bution while mixed forests showed a random distribution. Scots pine forests and beech forests displayed intermediate distributions, somewhere between the other two forest types. The species profile index reveals lower vertical structure diversity in the Monterey pine plantations and higher values in the natural forest types. These results conflict with those obtained using the standard deviation of tree height, which indicated that the highest vertical structure diversity corresponded to the beech forest and the lowest to the mixed forest. Tree heights in Mediterranean mixed forests are low (average of 6.8 m) although tree height class diversity is high. Diameters, however, are relatively homogeneous. Beech forests show high values for both vertical and horizontal structure indices.

Table 7 shows the stage of stand development for each forest type. This information is obtained using the traditional data from the Spanish NFI. Needless to

Table 7. Percentage of plots in the different stages of stand development for the four forest types studied in the province of Álava (Basque Country)

Stand development stage	Monterey pine plantation	Scots pine	Beech forest	Mixed forest
Even-aged	92.41	11.24	0.00	9.39
Two-aged	5.05	10.22	5.42	17.35
Uneven-aged	2.54	78.54	94.58	73.26

Radiata pine plantation

Others 31%
Pinus radiata 50%
Castanea sativa 6%
Quercus robur 13%

Beech forest

Others 26%
Fagus sylvatica 43%
Quercus faginea 6%
Ilex aquifolium 7%
Acer campestre 7%
Crataegus monogyna 11%

Scots pine forest

Others 18%
Pinus sylvestris 32%
Fagus sylvatica 6%
Juniperus communis 8%
Ilex aquifolium 8%
Crataegus monogyna 8%
Quercus ilex 9%
Quercus faginea 11%

Mixed forest

Others 30%
Quercus ilex 18%
Quercus faginea 18%
Pinus sylvestris 16%
Juniperus communis 11%
Crataegus monogyna 7%

Figure 4. Percentage of total Importance Value Index (IVI) corresponding to each of the different tree species in the four forest types studied in Álava province (Basque country). Species are specified when their IVI value is higher than 3.5%, otherwise they are summarized in "others".

say, the Monterey plantation forests are those with the highest percentage of plots within even-aged stands. In the province of Álava, the majority of natural forests are uneven-aged. This implies higher structural biodiversity and therefore a greater capacity to react against environmental changes and hazards.

Some indicators, such as IVI for tree and shrub species, combine composition and structure. The results are shown in Fig. 4 for tree species and in Fig. 5 for shrub species, and both are represented in percentage terms. It is interesting to note the different IVI distributions for dominant tree stands and mixed forest. Mixed forests display the greatest diversity of shrub structure and composition.

The vertical complexity index combines horizontal shrub structure and vertical tree structure (Table 5). Larger percentages in the higher vertical complexity classes indicate higher structural diversity. Scots pine forests and mixed forests are more diverse, while Monterey pine plantations are the least diverse (Fig. 6). The values for Beech forest are low since most of the stands only have one layer; hence the differences in vertical structure are minimal. Classes 7 and 8 are cha-

racterized by stands with intermediate values for tree crown cover, allowing light to reach the soil and promoting a rich understory shrub cover. This situation is typical of Mediterranean ecosystems and sub-Mediterranean pine forests such as Mediterranean mixed forests and Scots pine forests.

Dead wood

Dead wood was quantified for each species along with decay class and dead wood components for each forest type. Beech forests present the highest volumes of dead wood (Fig. 7), reaching levels of up to 10 m^3/ha. The highest volumes of dead wood were found for *Fagus sylvatica, Pinus sylvestris*, and *Quercus* species. Downed and standing trees made up at least 40% of the total dead wood, reaching as much as 70% in some forest types.

The most frequent dead wood decay classes were 3 and 4, accounting for nearly 70% of the total volume of dead wood. Therefore the stage of dead wood decay in this province is intermediate-high.
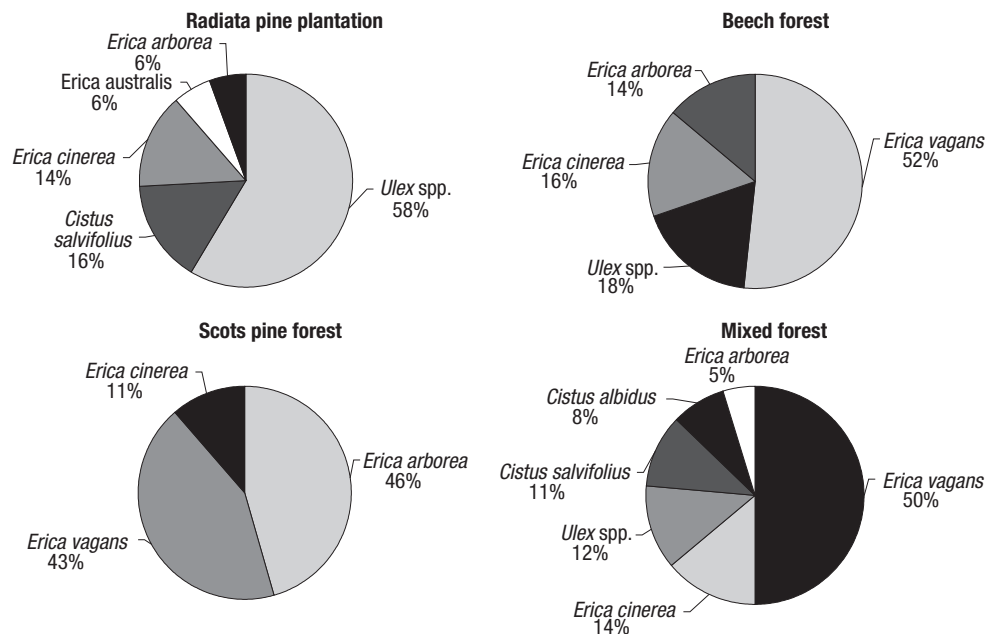
Figure 5. Percentage of total Importance Value Index (IVI) corresponding to each of the different shrub species in the four forest types studied in Álava province (Basque country). Species are specified when their IVI value is higher than 3.5% otherwise they are summarized in "others".
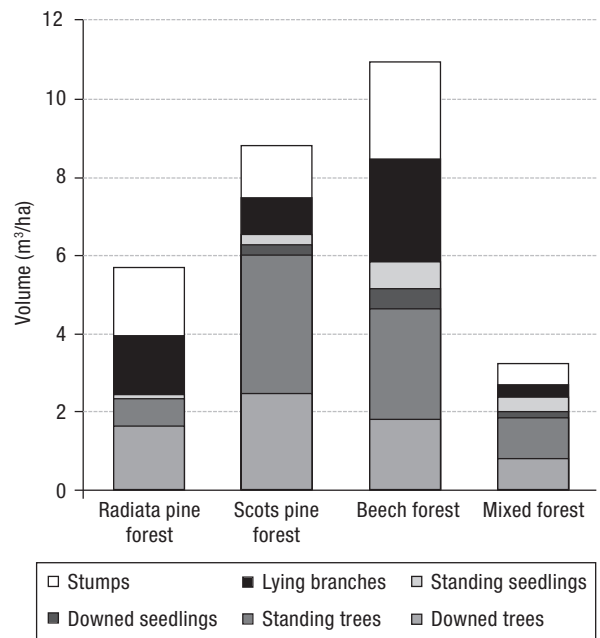
Herbaceous plant and ferns richness

The results obtained allow a comparison to be made between the different forest types in terms of richness (Fig. 8). Scots pine forests present the highest herbaceous species richness. They are characterized by open forest, which permits the development of this vegetative life form. Ground cover values also reveal high coverage as regards herbaceous plants and fern species.

Beech forests also present high richness values and comprise the largest surface area of all the forest types studied (which also affects the results). The shade in these forests permits the establishment of shade demanding herbaceous plants and ferns, while inhibiting
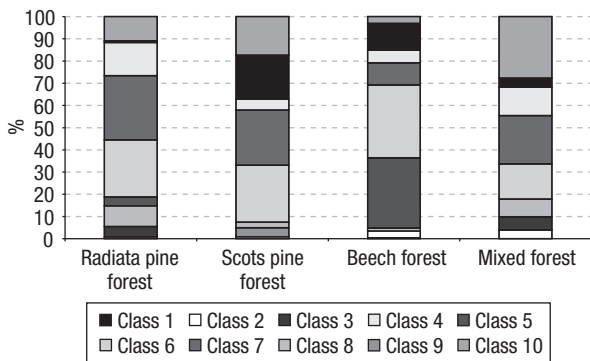
Figure 6. Vertical complexity index in the four forest types studied in Álava province (Basque Country): Percentage of plots of each class. Class1: 1 tree layer (L), Crown cover (Cc) < 50, and shrub cover (Sc) < 10; Class 2: 1L, Cc < 50, 10 ≤ Sc < 40; Class 3: 1L, Cc < 50, 40 ≤ Sc < 70; Class 4: 1L, Cc < 50, Sc ≤ 70; Class 5: 1L, Cc ≥ 50, Sc < 10; Class 6: 1L, Cc ≥ 50, 10 ≤ Sc < 40; Class 7: 1L, Cc ≥ 50, 40 ≤ Sc < 70; Class 8: 1L, Cc ≥ 50, Sc ≥ 70; Class 9: L ≥ 2, 0 ≤ Sc < 40; Class 10: L ≥ 2, Sc ≥ 40.

Figure 7. Volume of each dead wood component in the four forest types studied in Álava province (Basque Country).
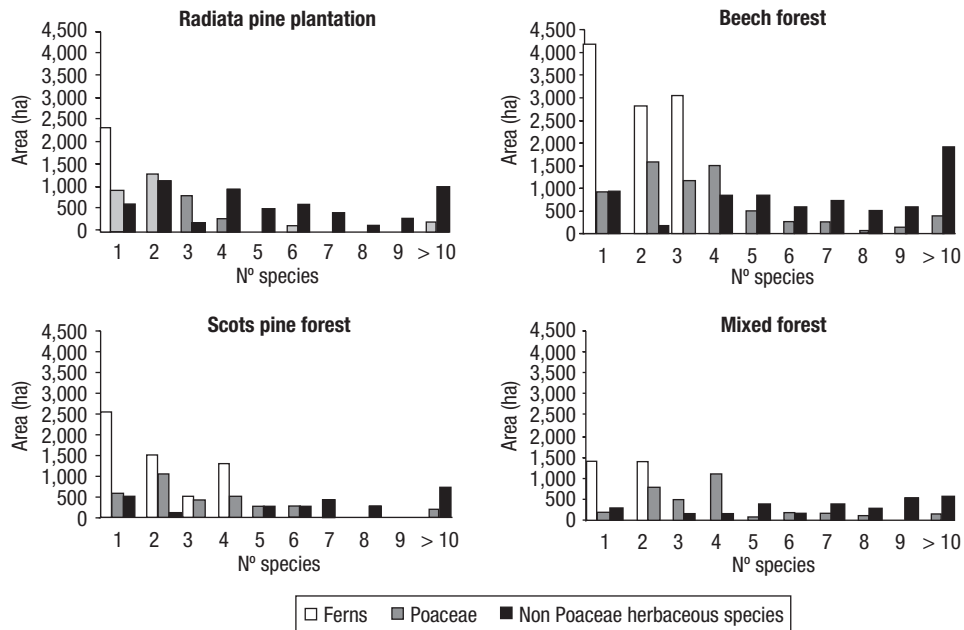
Figure 8. Number of herbaceous plant and fern species per area (ha) in the four forest types studied in Álava province (Basque Country).

the development of other woody species. Also worthy of note is the significant presence of non *Poaceae* species in the Monterey pine plantations.

Epiphytic lichens

Crustaceous lichen species are the most common, while fruticulous lichens are the least frequent (Fig. 9). Mixed forests contain the tree species which present the highest lichen richness.

The tree species displaying the highest abundance of lichens (and therefore the highest IAP) are: maple trees (*Acer monspessulanum* L*., Acer opalus* Mill.), whitebeam (*Sorbus aria* Linnaeus Crantz.), willows (*Salix caprea* L*., S. atrocinerea* Brot., etc.), oaks (*Quercus faginea*) beech (*Fagus sylvatica*) and hazelnut (*Corylus avellana* L.). The IAP for conifers is lower due to the location of conifer forests (lowlands and closer to populated areas) and the fact that in the area studied, they tend to be plantations.
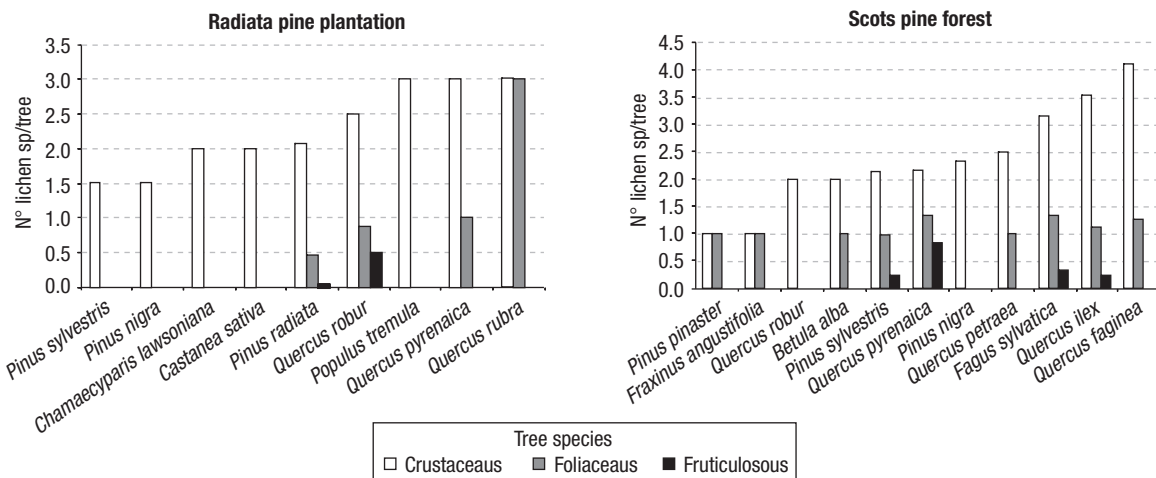
Figure 9. Number of lichens of the three morphological groups present on each tree species in two of the four forest types studied in Álava province (Basque Country).
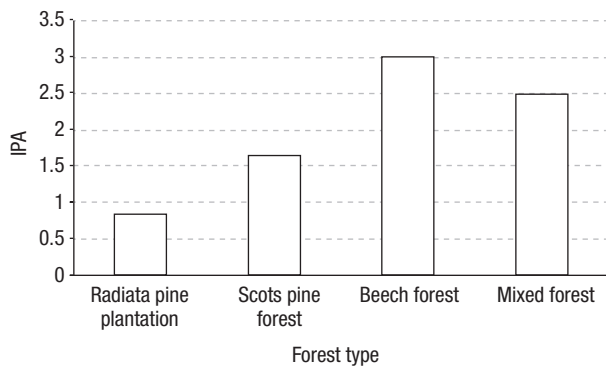
Figure 10. Average Index of Atmospheric Purity (IPA) in the four forest types studied in Álava province (Basque Country).

In Fig. 10 (the IAP of each forest type) the average is estimated. Beech forests present the highest values while Monterey pine forests display the lowest.

Statistical analysis of the main indices used to evaluate biodiversity in Álava province

The main groups of indicators in terms of the number of indices derived from them as well as their relative importance were analyzed: 1) tree and shrub species composition; 2) forest structure (horizontal and vertical structure); 3) dead wood.

Composition

Correlations between the different tree composition indices are very high, varying from 0.61 to 0.99 (Table 8). The reason for this is clear, since the variables used to calculate these indices are the same, even though the infor-

Table 8. Spearman correlation coefficients for composition indices studied in the province of Álava (Basque Country). Only significant coefficients at the 0.005 level are shown in the table

	N	H	$1 - D$	D_{MG}	$1 - D_{BP}$	M_i
N	1	0.95	0.93	0.98	0.91	0.61
H	0.95	1	1.00	0.94	0.99	0.65
$1 - D$	0.93	1.00	1	0.93	1.00	0.64
D_{MG}	0.98	0.94	0.93	1	0.91	0.61
$1 - D_{BP}$	0.91	0.99	1.00	0.91	1	0.64
M_i	0.61	0.65	0.64	0.61	0.64	1

N: Number of species. H: Shannon-Weaver index. D: Simpson index. D_{MG}: Margalef index. D_{BP}: Berger-Parker index. M_i: Mingling index.

mation provided for each one is complementary (Warwick and Clarke, 1995). Due to these high correlations, only one component is extracted in the Principal component analysis (PCA) in which 84.08% of variance is explained. However a further analysis forcing a second component reveals that this second component is mainly explained by Mingling index, then 93.16% of the variance is explained (Table 10). The Mingling index is the only one which takes into consideration the spatial distribution of the species as well as the composition.

Forest structure

Although vertical and horizontal structure indices are generally correlated, the species profile index shows little or no correlation (Table 9) with neighbour indices and diameter or height skewness, nevertheless the Spearman coefficient for standard diameter deviation (0.41) and height deviation (0.49) are relatively

Table 9. Spearman correlation coefficients of main structure indices studied in the province of Álava (Basque Country). Only significant coefficients at the 0.005 level are shown in the table (ns: not significant coefficient)

	I_{CE}	W_i	*Shrub PsV*	A	$S(D)$	$Sk(D)$	$S(H)$	$Sk(H)$
I_{CE}	1	−0.11	ns	0.09	0.06	ns	0.16	ns
W_i	−0.11	1	−0.15	ns	ns	0.06	ns	ns
Shrub PsV	ns	−0.15	1	ns	−0.22	0.09	−0.19	0.17
A	0.09	ns	ns	1	0.41	0.23	0.49	ns
$S(D)$	0.06	ns	−0.22	0.41	1	0.10	0.74	ns
$Sk(D)$	ns	0.06	0.09	0.23	0.10	1	ns	0.41
$S(H)$	0.16	ns	−0.19	0.49	0.74	ns	1	−0.31
$Sk(H)$	ns	ns	0.17	ns	ns	0.41	−0.31	1

ns: not significant coefficient. I_{CE}: Clark and Evans index. W_i: Gadow's uniform angle index. *Shrub PsV*: Shrub pseudo-volume. A: Species profile index. $S(D)$: standard deviation of tree diameter. $Sk(D)$: skewness of tree diameter. $S(H)$: standard deviation of height diameter. $Sk(H)$: Skewness of tree height.

Table 10. Principal Component Analysis. Rotated Component matrix for composition indices studied in the province of Álava (Basque Country)

	PC 1	PC 2
H	0.92	0.38
D	0.91	0.27
D_{BP}	0.91	0.26
D_{MG}	0.88	0.40
N	0.85	0.40
M_i	0.33	0.94

Rotation method: varimax with Kaiser normalization. PC 1: Principal component 1. PC2: principal component 2. N: Number of species. H: Shannon-Weaver index. D: Simpson index. D_{MG}: Margalef index. D_{BP}: Berger-Parker index. M_i: Mingling index.

high. Tree diameter and height skewness are poorly correlated with the rest of the indices. Finally, the shrub pseudo-volume is correlated with horizontal indicators (diameter deviation and Gadow index) but also with height deviation.

Three components were extracted by PCA and together, these account for 58.87% of the variability in the original data. Diameter and height deviation as well as the Species profile index contribute in a higher proportion to the variance for the first component (PC1). Height skewness and diameter skewness show an important contribution in component two (PC2), whereas spatial structure indices (Clark and Evans and Gadow indices) together with the shrub pseudo-volume show the greatest contribution in the third component (PC3).

These conclusions can be drawn using 2D biplots (Fig. 11). Three different groups of close variables within the group can be observed: (i) Species profile index, height and diameter deviation and (ii) Spatial structure indices (which are opposite due to their values in the indices) together with shrub pseudo-volume and (iii) Height and diameter skewness. The results show that the higher the shrub-pseudo-volume, the lower the Gadow index (indicating regularity in the forest structure) and height and diameter deviation.

Dead wood

Dead wood volumes and number of pieces per hectare (number of dead standing trees, number of dead standing saplings, etc.) are highly correlated. A PCA analysis of components volume was performed. The analysis shows that two components were extracted, accounting for 52.83% of the variability in the original data. There is a notable difference between sapling deadwood types (standing and downed) and the rest of the dead wood types (Fig. 12).

Discussion

Methodology

Forest biodiversity is fundamental to the ecological, economic and social well-being of earth's civilisations,
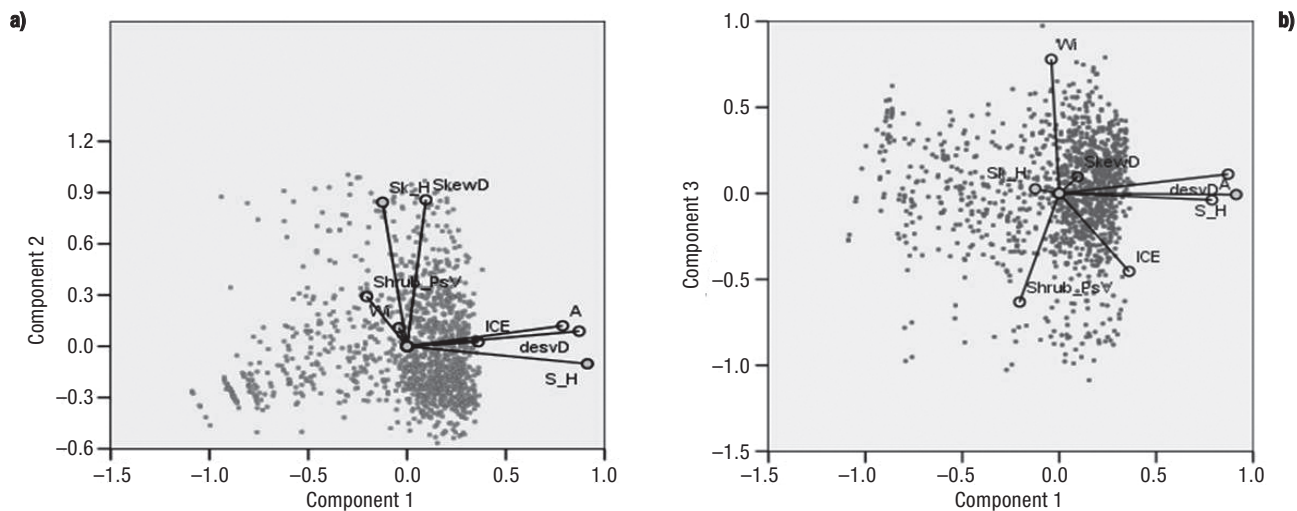
Figure 11. 2D biplots of the principal component analysis of the main structure indicators. Total explained variance of Biplot a: 43.58% (25.49% PC1 + 18.09%PC2) and of Biplot b: 40.79% (25.49% PC2 + 15.30%PC3). ICE: Clark and Evans index. Wi: Gadow's uniform angle index. Shrub-PsV: Shrub pseudo-volume. A: Species profile index. desvD: Standard deviation of tree diameter. SkewD: Skewness of tree diameter. S_H: Standard deviation of height diameter. Sk_H: Skewness of tree height.
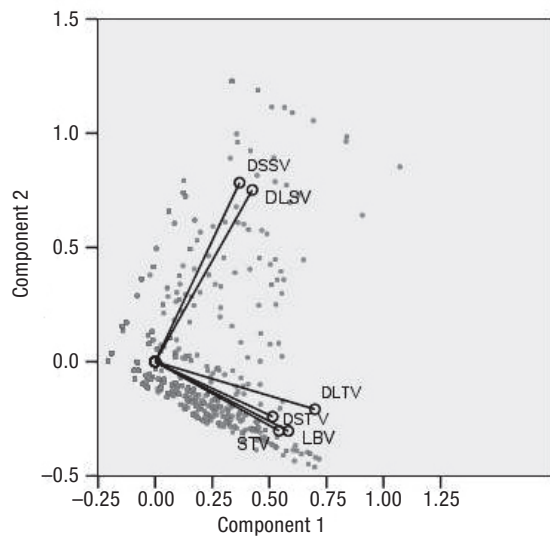
Figure 12. 2D Biplot of the principal component analysis of dead wood volume according to type. Total explained variance 52.83% (28.44% PC1 + 24.39%PC2). DLS V: dead lying saplings volume. DLT V: dead lying tree volume. DSS V: dead standing saplings volume. DST V: dead standing tree volume. LB V: lying branches volume. ST V: stumps volume.

though it is threatened to a serious degree in most countries (Winter *et al.*, 2011). However, biodiversity monitoring and assessment is a relatively new development in many countries. The proposed methodology has been elaborated taking into account the advances made through European initiatives as well as the experience and results of the Spanish NFI. The new biodiversity variables proposed for the NFI improve the ecosystem information, permitting a more detailed analysis of forest composition and structure and allowing us to estimate fundamental variables such as dead wood.

This methodology could be applied to inventories based on concentric plots in temperate climates. Other kinds of inventories such as those based on angle count plots could adopt some of the groups of indicators suggested in this paper but additional data would need to be recorded. For example, to obtain spatial structure indices, the position of every tree would have to be recorded. In any case, specific characteristics (such as thresholds regarding dead wood) must be adapted for each inventory. The majority of the harmonized indicators proposed for NFIs (Chirici *et al.*, 2011) are contained in this methodology, although some of them need a simple function to obtain the reference harmonized indicator due to the specific characteristics of the Spanish NFI. For instance, in the COST E-43 definition of standing dead wood volume, dead stems of

more than 10cm at breast height and branches are excluded. In the Spanish NFI, therefore, to harmonize the estimated standing dead wood volume in accordance with this European reference definition, branches and trees with diameters between 7.5 and 10 cm must not be taken into account.

The average survey duration per plot in the traditional NFI (not including the time required to reach the study area and locate the plot) is approximately 1 hour and 40 minutes, while the average monitoring time per plot for the additional biodiversity measurements in the framework of NFI is about 50 minutes which is an admissible time investment for the amount of information acquired.

Current biodiversity methodology must be seen as a "dynamic project" that needs to be adapted to national and international requirements (Ferris and Humphrey, 1999). Analysis of the monitoring data may reveal a necessity to modify this methodology in order to optimize the costs, feasibility, quality and quantity of the recorded data.

Many indices for assessing biodiversity have been described in international literature on the subject. In this paper, some of the more suitable indices for NFI's are discussed. The use of the different indices and the incorporation of new ones based on the variables monitored must also be considered a dynamic process. However, to select a definitive list of indicators, a crucial aspect is the ability to assess biodiversity changes at both national and international level (through the evolution of the different indices over time) and to compare the biodiversity status between regions and countries.

In NFIs based both on concentric plots and angle count plots, not all trees are monitored. Therefore additional measurements are needed to obtain spatial structure indices. Subsamples of five random tree-point distances, five tree-tree distances and the angles between them were measured and the species of each tree was recorded. However, this was found to be very time consuming and so alternative methodologies were assessed. The new approach selected provides a large amount of information and is much more cost effective. In this approach, the position of each tree is recorded in one of the following concentric circles: 25, 20, 15, 10 or 5 m. The size of the circle will depend on tree density; selecting the minimum concentric radius within which there are at least 20 trees. Using this new methodology, structural indices can be calculated.

Though many authors consider that the higher presence of dead wood in forest, the higher the naturalness

of forest (Schuck *et al*., 2004), in Mediterranean forest types, dead wood volume should not rise above certain thresholds due to the increased risk of forest fires or harmful organisms (pest and diseases). Therefore, this is a key variable which, where present, should be analyzed and evaluated taking into consideration forest type as well as climatic variables.

As regards dead wood variables, the volume of dead standing and downed trees has traditionally been calculated using the same equations (Spanish NFI) for both stems and branches. However, this leads to an overestimation of the volume of branches. Hence, a scale was defined which considers the branches remaining on the trees and the volume is reduced accordingly. Line intersect sampling (Warren and Olsen, 1964) is frequently used to estimate downed branches (Böhl and Brändli, 2007) although due to the irregular distribution patterns of dead wood in Spanish forests (high bias) and the inefficiency associated with combining two different monitoring methods, this approach was rejected. The two additional dead wood decay classes proposed have led to an improvement in the calculation of dead wood volume and therefore are highly recommended, as is the new "coppice stump" category for Mediterranean countries.

Recording herbaceous plant and fern richness data was hindered by the fact that the NFI is undertaken throughout the year and yet many species can only be identified at certain times of the year. Therefore, the results for a given area were highly dependent on the season in which the inventory was carried out. Furthermore, the field work team required a high degree of expertise.

Recording the data on epiphytic lichen was the most time-consuming activity and what is more, intensive training was required in order to obtain reliable results. Moreover, correlations with other biodiversity parameters were poor and it was often difficult to interpret the results. Hence, it has been agreed that neither herbaceous plant/fern richness nor epiphytic lichen data will continue to be measured.

As regards threatened species, it should be borne in mind that the systematic NFI design is not the best tool for assessing these (more appropriate inventory designs exist), although at larger scales satisfactory approaches are possible.

Recently, other information has been added to the field data collection but this has not been processed as yet. The new variables are "invasive species" and forest age. Many authors highlight the importance of invasive species (MacDougall and Turkington, 2005; Funk, 2008; Kolar and Lodge, 2001). In the Spanish NFI, a survey of invasive species is considered necessary given their increased aggressiveness due to global change. The presence and number of all invasive woody plants as well as some herbaceous plants are recorded. The number of invasive tree species is recorded in a 10 m radius subplot, invasive shrubs in a 5 m radius subplot and invasive herbaceous species in a 1m subplot. Presence of all these species is recorded in the 25 m Spanish NFI plot.

The COST E-43 identifies forest age as a biodiversity core variable. The reference definition for NFIs of this COST Action of forest age has been adopted (mean age of the 100 trees per hectare with the largest diameters, independent of stand or forest structure, tree age distribution or management), (Chirici *et al*., 2011). The age of the dominant trees is calculated from growth rings on a core extracted using an increment borer and analyzed in the laboratory. An in depth study into older living trees is being developed in the Spanish NFI through the data obtained.

To complement the biodiversity measurements, another parameter has been taken into account in the Spanish NFI, namely, the impact of browsing. This parameter was selected due to its impact on the decay process and the fact that certain species are affected more than others. Browsed species and browsing degree are registered on a scale of 0-5.

Statistical analyses of the indicator relationship

Ground cover, dead wood, herbaceous plant and fern richness, threatened species, epiphytic lichens and microsite groups of indicators are based exclusively on specific biodiversity measurements, while composition and structure are only partially based on this information.

Measurements related to structure and dead wood consumed nearly half of the additional time spent on biodiversity measurements. For this reason, composition, structure and dead wood have been analysed in depth.

Composition

Diversity composition indices estimation can be derived from the traditional NFI with the exception of

the Mingling index. This index makes a valuable contribution to the overall information (as shown by the PCA analysis and the fact that it considers spatial distribution). It should be mentioned that although all the information is derived from the traditional NFI, it is important to undertake an in depth study of the national species list for the purposes of the biodiversity assessment. This task has recently been carried out in the case of the Spanish NFI, especially for shrub species.

Structure

The main structure parameters (height, diameter and cover) can be derived from the traditional NFI inventory. However, to calculate spatial structure indices, which contribute important information (as shown by the PCA analysis and biplots), additional measurements are required. The statistical analysis yields two important findings with regard to the indices calculated using the traditional NFI data:

i)   Although there are correlation between the standard deviation of height and diameter and the species profile index, the use of this index is not justified when there is height information of every tree. The species profile index is a widely used index but has also been criticized (Barbeito *et al.*, 2009) because it displays artificial layers which may not reflect the reality and therefore, the conclusions derived from its use may be misleading. Standard diameter and height deviation is recommended as an index of horizontal and vertical structure when there is information of every tree as all the available information is used. On the contrary, when there is only information about the height layer to which each tree belong, then, the species profile index could be used as a vertical indicator.

ii)   Diameter and height skewness provide interesting complementary information as shown by the statistical analysis. Sterba (2008) has recently highlighted the importance of these parameters. For example, a change from positive to negative diameter skewness values seems to imply a change from a regular to an irregular tree distribution.

Dead wood

The PCA and biplot analysis yielded some interesting results as regards the volume of sapling dead wood, which was found to vary due to the irregular dis-

tribution. In many inventories, sapling dead wood is not measured due its low contribution to total dead wood. However, as shown in this paper, it provides interesting complementary information and what is more, it is a particularly useful parameter for analysing regeneration success.

PCA analysis provides a particularly useful tool for selecting indicators by revealing the behavior of each one. It is especially relevant in the case of NFIs since the large amounts of data involved necessitate the use of statistical analysis as well as that fact that the indicators used must be coherent for every forest type analyzed.

Acknowledgements

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