Work Package 2

Procedures and models
to estimate the biomass of forest stand

Procedure e modelli
di stima delle biomasse delle cenosi forestali

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Above-ground tree phytomass prediction and preliminary shrub phytomass assessment in the forest stands of Trentino

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SUMMARY - *Above-ground tree phytomass prediction and preliminary shrub phytomass assessment in the forest stands of Trentino* - Despite the importance that forest resources have achieved in Italy from both the economic and environmental perspectives, quantitative surveys of tree and shrub phytomass are still not widely applied and are usually devoted to few species and small areas. This situation also holds in the Province of Trento, notwithstanding its long tradition in forest inventorying aimed at forest management planning. The present paper deals with some investigations performed in the forests of Trentino with the aim of improving the quantification of forest stand phytomass through the construction and estimation of suitable prediction models for any species or species group of interest. A practical application to predict the total volume and the above-ground tree phytomass in two intensive monitoring areas of the Province of Trento is considered. Finally, the paper deals with an observational study performed on the above-ground phytomass of shrub stands in Trentino, classified in accordance with the forest types adopted by the National Forest Inventory.

RIASSUNTO - *Modelli di previsione della fitomassa arborea epigea e osservazioni preliminari della fitomassa arbustiva epigea nelle formazioni forestali del Trentino* - Sebbene l'importanza ambientale ed economica delle risorse forestali sia in Italia ormai ampiamente riconosciuta e condivisa, le indagini quantitative sulle fitomasse forestali arboree e arbustive sono tuttora poco numerose e risultano limitate a poche specie e a territori molto circoscritti. Questa situazione permane anche nel territorio della Provincia di Trento, nonostante la lunga tradizione di inventariazione dei soprassuoli forestali con finalità di pianificazione e gestione. Il presente lavoro riporta i risultati di uno studio effettuato nelle foreste del Trentino con lo scopo di migliorare la quantificazione della fitomassa arborea epigea attraverso la formulazione e la stima di modelli previsionali opportunamente distinti per specie o per gruppi di specie. Il lavoro descrive inoltre un'applicazione della metodologia proposta per la stima del volume totale e della fitomassa arborea epigea in due aree di monitoraggio intensivo della Provincia di Trento. Il lavoro riporta infine i risultati di una campagna di osservazioni e misure della fitomassa epigea relativa alle formazioni arbustive del Trentino, classificate secondo la tipologia prevista nell'ambito dell'Inventario Forestale Nazionale.

Key words: tree phytomass, shrub, prediction models, least-square estimation, Trentino
Parole chiave: fitomassa arborea, arbusti, modelli previsionali, metodo minimi quadrati, Trentino

1. INTRODUCTION

Interest in preparing quick and accurate phytomass estimation procedures has greatly increased during recent decades owing to the environmental, economic and social importance of this renewable resource (Johansson *et al.* 1993; Pettenella & Picciotto 1993; Schlamadinger *et al.* 1996; Hall 1997; Anderle *et al.* 2002; Bjørnstad & Skonhoft 2002; Hellrigl 2002; Mori 2003). Accurate phytomass estimates are needed to quantify the carbon amount stored in forest ecosystems, in order to subsequently evaluate the forest's role in mitigating the release of carbon dioxide into the atmosphere. Moreover, from an economic point of view, interest in quantifying forest phytomass has arisen from recent awareness of the economic importance of the carbon sequestration capacity in terrestrial ecosystems as well as the awareness that woodlands represent one of the most important sources of renewable energy, consequently producing invaluable social and environmental benefits. Finally, forest phytomass quantification is necessary in research studies on the productivity of terrestrial ecological systems, related nutrients, energy fluxes and environmental monitoring.

Notwithstanding this, the procedures usually adopted to estimate forest stand phytomass are far from being adequate, both at the national and international level. At the national level, the estimation of forest stand phytomass in large areas is usually performed by means of factors that convert commercial volumes to fresh and/or oven-dry weight values. In most cases, these factors represent mean values quoted from literature and they are used without considering stand composition, tree-size distribution or the type of commercial volume. As a consequence, an evaluation of the accuracy and reliability of such estimates is very hard, or even impossible. The same approach is usually adopted at international level as well. Obviously, in these cases, the problems are exacerbated by the need to integrate and harmonise data usually collected without homogeneous criteria, procedures or measurement standards (UN-ECE/FAO 2000).

From a scientific point of view, the Italian literature on forest phytomass contains only a few published papers which are usually restricted to some selected species and small areas (Colleselli 1974; Hellrigl 1974; Calamini *et al.* 1983, 1989; Menguzzato & Tabacchi 1988, 1990, 1995; Bezzi *et al.* 1991; Brandini & Tabacchi 1996; Amorini *et al.* 2000; Calamini & Gregori 2001; Ciancio *et al.* 2002). Surprisingly, no paper is devoted to tree and shrub phytomass estimation in the forests of Trentino, in spite of the area's long tradition of forest stand inventorying for forest management.

Recently, a study aimed at improving the quantification of forest stand phytomass at a national level has been launched within the framework of the national research project *Progetto Ri.Selv.Italia* (website: www.isafa.it), while a similar investigation at provincial level, referred to as the EFOMI project (Ecological evaluation of forest stands assessed by integrated monitoring), is running in the Province of Trento. Both studies are mainly focused on the construction and estimation of prediction models for some selected species or species groups. The EFOMI project also aims to collect information about the above-ground phytomass of shrub stands in the Province of Trento.

The methodologies adopted in the EFOMI project are considered in this paper and the main findings of the research are reported and discussed. Section 2 is devoted to the construction of prediction equations for above-ground tree phytomass in the forest stands of Trentino. General considerations about design-based and model-based procedures, the choice of variables, model building, tree selection procedures, field and laboratory measurements and estimation techniques are discussed from sub-section 2.1 to 2.6, while the resulting prediction equations, regarding seven single species and two groups of species are reported in sub-section 2.7. Subsequently, in section 3, the resulting equations are applied to estimate the total above-ground tree phytomass of two intensive monitoring areas situated in Lavazè Pass and in Pomarolo (Trento). Moreo-

Tab. 1 - List of notations and standards with the definitions of the groups of species considered in the work.
Tab. 1 - Legenda dei simboli e delle unità di misura utilizzate e definizioni delle classi di specie considerate nel presente studio.

n= number of items
d= diameter at breast height (cm)
h= height (m)
Stem V= Stem (diameter > 5 cm) Volume (dm^3)
Branch V= Branch (diameter >5 cm) Volume (dm^3)
Stump V= Stump Volume (dm^3)
Stem + Branch V [V]= Stem (diameter > 5 cm) and Branch (diameter >5 cm) Volume (dm^3)
Branch FW= Branch (diameter > 5 cm) Fresh Weight (kg)
Slash FW= Slash (diameter < 5 cm) Fresh Weight (kg)
Dead FW= Dead branch Fresh Weight (kg)
Stem DW= Stem (diameter > 5 cm) Dry Weight (kg)
Branch DW= Branch (diameter > 5 cm) Dry Weight (kg)
Stem + Branch DW [w1]= Stem (diameter > 5 cm) and Branch (diameter >5 cm) Dry Weight (kg)
Slash DW [w2]= Slash (diameter < 5 cm) Dry Weight (kg)
Dead DW [w3]= Dead branch Dry Weight (kg)
Stump DW [w4]= Stump Dry Weight (kg)
Cut DW= Cut wood Dry Weight (kg)
AG DW [wtot]= Above-Ground Dry Weight (kg)
CV= Coefficient of Variation
Ostrya carpinifolia and other similar tree species= *Ostrya carpinifolia*, *Carpinus* sp., *Quercus ilex*, *Quercus pubescens*, *Fraxinus* sp., *Robinia pseudoacacia*
Castanea sativa and other similar tree species= *Castanea sativa*, *Acer* sp., *Salix* sp., other hardwoods

ver, Section 4 contains a description of the procedures adopted to investigate forest shrubland in the Province of Trento. The main results of these preliminary investigations are also discussed. Final remarks are given in section 5. Table 1 contains a list of the notations and standards adopted throughout the paper, together with the definitions of the two groups of species considered in the work.

2. THE PREDICTION OF ABOVE-GROUND TREE PHYTOMASS

2.1. General considerations

The exact quantification of the above-ground phytomass of a single tree is possible only through the laborious task of felling and weighing the whole tree. In order to reduce the high costs of complete weighing, the weighing of some parts of the tree is usually avoided by means of suitable practical and geometrical considerations (see sub-section 2.5). It is worth noting that these procedures do not give rise to any estimate (in a statistical sense) of the above-ground phytomass, but rather they may be simply viewed as a way to make phytomass quantification easier. Alternatively, Valentine *et al.* (1984) and, more recently, Gregoire *et al.* (1995) propose the use of a probabilistic sampling scheme (so-called *randomised branch sampling*) to select a path from the butt of the felled tree to a terminal bud. Subsequently, the above-ground phytomass is estimated by measuring the quantity of interest on the discs selected along the sampled path by means of importance sampling. This procedure provides a design-unbiased estimator of the above-ground phytomass of the tree together with an unbiased estimator of the sampling variance.

Both these strategies are quite distinct from the most common and immediate method of relating the whole or component phytomass to combinations of easily measured size characteristics of the tree (such as stem diameter at breast height and tree height) by means of a regression model (see e.g. Parresol 1999 and references wherein). With this approach, destructive measurements are necessary only for a restricted set of trees, to estimate the parameters of the regression model in such a way as to determine the prediction equation. Subsequently, for any single tree, a prediction of its above-ground phytomass may be readily performed by means of the prediction equation without performing any destructive measurement of the tree.

When the objective is to estimate the above-ground phytomass of a population of trees in a monitoring area, direct measurements or randomised branch sampling cannot be performed on each tree. In this case, a feasible approach is to restrict direct measurements or branch sampling to a sample of trees selected from the population by means of a suitable probabilistic scheme. This strategy gives rise to a design-unbiased estimator of the total above-ground phytomass with a sampling variance split into two components, one due only to the selection of trees from the population and the other due to both to tree and branch sampling. Obviously, the second component vanishes if the phytomass of the selected trees is obtained using direct measurements. Usually, in order to avoid the destruction of a large stand of trees in the area, the number of sampled trees is set as small as possible, thus increasing both the variance components. On the other hand, if the phytomass is predicted by means of previously constructed equations (without destructing any tree in the area but rather on the basis of some quantitative, easily measured, characteristics of the trees) the predictions may be quickly performed for all the trees in the stand. If the prediction model is true, the strategy gives rise to an unbiased predictor of the total above-ground phytomass with a sampling variance totally due to the uncertainty of the phytomass predictions (see section 3).

However, even if the prediction models, when previously fitted to data, exhibit strong relationships between phytomass and predictor variables, there is still a considerable risk in adopting the resulting equations (Schreuder *et al*. 2001). Indeed, the predictions may be model-biased, which often occurs when a prediction equation is fitted to a species in one physiographic growing region, but applied to a different physiographic region (Gregoire 2004, personal communication). In a simulation study, Schreuder *et al.* (1990) showed unacceptable levels of bias when estimating the phytomass over a whole area by means of these equations. Accordingly, while the use of destructive methods ensures design-unbiased estimators of the phytomass with presumably high levels of variance (owing to the reduced set of sampled trees), the alternative use of prediction equations ensures presumably smaller variances (owing to the complete investigation of the trees) but with presumably relevant levels of bias. Thus, since the accuracy of an estimation technique is determined by the joint effect of variance and bias, there is no way to establish the efficient procedure to be used in general. However, at least from a practical point of view, the use of prediction equations previously constructed by means of separate surveys seems to be the most convenient way of inventorying monitoring areas, since it avoids any destructive and time-consuming phytomass measurements.

2.2. Variable definition

In order to facilitate the measurement procedures by means of a unified protocol, the same survey variables were considered in the EFOMI project for both coniferous and broadleaf species. More precisely, for the commercial volume, the volume of stem and branches with a minimum diameter of 5 cm (say v) was considered as the object variable, while, for the above-ground tree phytomass, its total amount (say w) was partitioned into some parts: the dry weight of the stem and branches with a minimum diameter of 5 cm (say w_1), the dry weight of the slashes with a maximum diameter of 5 cm (say w_2), the dry weight of the stem and dead portions of branches (say w_3) and the dry weight of the stump (say w_4).

It is worth noting that these variables arose as a compromise between the need to achieve an accurate description of the phytomass components and the need to reduce measurement effort. For this reason, stems and large branches with a minimum diameter of 5 cm were divided from the small branches and twigs, in order to avoid the difficulty of separating stems from branches, which is common in most broadleaf and certain coniferous trees (IFNI 1984). For the same reason, the woody parts and the bark of stems and branches were not separated, while, owing to the high cost (particularly for coniferous) of collecting separate data for foliar and wood components, the aggregate value of crown phytomass was considered without dividing the leaves from the woody parts, as should be appropriate for measuring dry weight and related organic carbon content. As a consequence of these choices, data collection of deciduous species was carried out when the trees were fully leaved, whereas, for the coniferous species (except the larch) and evergreen deciduous trees the collection was performed without seasonal constraints.

Finally, as to the species or group of species to be modelled, these were determined on the basis of the resulting abundance in the forests of Trentino. To this purpose, the information collected from the First National Forest Inventory (MAF-ISAFA 1988) as well as information arising from local forest plans and other observational studies was adopted. Seven main species were finally identified (spruce, fir, larch, Scots pine, black pine, Swiss stone-pine and beech) together with two groups of species, the first group comprising hornbeams and the second comprising chestnuts (Tab. 1).

2.3. Model construction

As concerns the structure of the prediction models, it is well known from past experience (see *e.g.* Parresol 1999 and references therein) that the vector of phytomass components, say $\mathbf{w}= [w_1, w_2, w_3, w_4]^T$ may be suitably predicted as a linear function of $\mathbf{u}= [u_1, ..., u_l]^T$, where, in general, u_1=1 (intercept) and $u_2, ..., u_l$ are combinations of diameter at breast height (d) and/or the total height (h) of the tree. Accordingly, the multivariate multiple regression model predicting **w** on the basis of **u** may be written as

$$\text{(1)} \qquad \mathbf{w}^T= \mathbf{u}^T\mathbf{B}+\boldsymbol{\eta}^T$$

where $\boldsymbol{\eta}= [\eta_1, \eta_2, \eta_3, \eta_4]^T$ is the vector of the four error terms with mean vector **0** and variance-covariance var($\boldsymbol{\eta}$), while **B** is a matrix of order lx4 whose jk-element b_{jk} represents the regression coefficient quantifying the effect of u_j on w_k (j= 1, ..., l; k= 1,2,3,4).

Since heteroskedasticity of errors invariably occurs in phytomass data, the variance for any η_k is usually assumed to be proportional to u_2^β, where usually $u_2= d^2h$ or $u_2= d^2$ and β is an additional parameter of the model (see e.g. Gregoire & Dyer 1989). Although not necessary, it is customary to adopt β= 2 as a good approximation for the true β value (see e.g. Cunia 1964; Ouellet 1983; Cunia & Briggs 1984; Meng & Tasai 1986; Williams & Gregoire 1993). Thus, it seems quite natural to extend such an assumption to the covariances between error terms, in such a way that var($\boldsymbol{\eta}$) may be rewritten as

$$\text{(2)} \qquad \mathrm{var}(\boldsymbol{\eta}) = u_2^2\, \boldsymbol{\Sigma}$$

where $\boldsymbol{\Sigma}$ is a four-symmetric matrix of constants.

Obviously, from (1) and (2), the multiple linear regression model predicting the total phytomass $w= \mathbf{w}^T\mathbf{1}$ on the basis of **u** becomes

$$w = \mathbf{u}^T\mathbf{b}+\eta$$

where **1** represents the four-vector of unit components, $\mathbf{b}= \mathbf{B1}$ is the l-vector whose j-element b_j represents the regression coefficient quantifying the effect of u_j on w(j= 1, ..., l) and $\eta= \boldsymbol{\eta}^T\mathbf{1}$ represents the error term for the whole phytomass which is the sum of the error terms related to each component. Obviously, from (2) the variance of η becomes

$$\mathrm{var}(\eta) = u_2^2\sigma^2_w$$

where $\sigma_w^2= \mathbf{1}^T\,\boldsymbol{\Sigma}\mathbf{1}$.

For β= 2, the heteroskedasticity of model (1) induced by assumption (2) may be straightforwardly bypassed by using the transformed vectors $\mathbf{x}= u_2^{-2}\mathbf{u}$ and $\mathbf{y}= u_2^{-2}\mathbf{w}$, in such a way that model (1) is reduced to

$$\text{(3)} \qquad \mathbf{y}^T= \mathbf{x}^T\mathbf{B}+\boldsymbol{\varepsilon}^T$$

in which now the vector of error terms $\boldsymbol{\varepsilon}= u_2^{-2},\boldsymbol{\eta}$ has a variance-covariance matrix equal to $\boldsymbol{\Sigma}$. Thus, model (3) represents a very simple multivariate multiple regression model with homoskedastic errors, and its parameters **B** and $\boldsymbol{\Sigma}$ may be straightforwardly estimated by means of ordinary least-squares (see sub-section 2.6).

A model analogous to (1) is also adopted to predict the stem and branch volume of a tree, say v. In this framework, v is usually supposed to be a linear function of **u**, in such a way that (1) now reduces to the multiple regression model

$$\text{(4)} \qquad v = \mathbf{u}^T\mathbf{c}+\varsigma$$

in which ς represents the error term with mean 0 and variance var(ς), while **c** is the *l*-vector whose *j*-element c_j represents the regression coefficient quantifying the effect of u_j on v (j = 1, ..., l). Also in this case, in analogy with (2), it is customary to model the heteroskedasticity of errors in such a way that

$$(5) \qquad \text{var}(\varsigma) = u_2^2\sigma_v^2$$

where σ_v^2 is a constant. Once again, the heteroskedasticity of model (4) induced by assumption (5) is bypassed by using $\mathbf{x} = u_2^{-2}\mathbf{u}$ and $z = u_2^{-2}v$, in such a way that model (4) is reduced to

$$(6) \qquad v = \mathbf{x}^T\mathbf{c}+\varepsilon$$

where the error term $\varepsilon = u_2^{-2}\varsigma$ has variance σ_v^2.

The predictor variable adopted in this work was the product of the square diameter and the total height, say $u_2 = d^2h$, even if a further variable was sometimes added, consisting again in a combination of the first two powers of d and h. The entry of a second variable into the model was not determined by a rigid statistical procedure (such as the well-known Akaike criterion) but rather by looking at the standard errors of the regression coefficients as well as the residual distribution and on the basis of practical and dendrometric considerations (e.g. when too many predictions obtained by the means of the unique predictor d^2h turn out to be outside the range).

2.4. *Tree selection for felling*

In a set of seminal papers, Cunia (1979a, 1979b and reference wherein) considers the problem of selecting a representative sample of trees when the objective is to construct prediction equations to be subsequently used in forest inventories.

The major concerns of the author regard the use of standard regression techniques when trees are selected by probabilistic sampling schemes. Indeed, one basic assumption of the regression model is the independence of the sampled values of the interest variable. On the other hand, since the most common sampling schemes are without-replacements schemes, they invariably entail dependence among these values. Moreover, samples that are representative from a design-based point of view, from which valid estimates of population totals or means may be obtained, may not be representative in the regression analysis, owing to the uneven distribution of selected trees over the ranges of the predictor variables.

In accordance with these considerations, the most common tendency is to adopt purposive selection procedures with the aim of choosing a moderately large set of trees in which the observed values of the predictor variables (usually stem diameter at breast height and tree height) may cover the whole ranges of these variables. As a consequence of this strategy, the observed values of the predictor variables are no longer random variables but constitute a matrix of constants. Moreover, from a more practical view, this strategy is likely to save time and costs in the serious operational difficulties of measuring phytomass as well as ensuring reliable predictions. Indeed, as pointed out by Cunia and Briggs (1984), outside-of-range predictions are not recommended "because regression functions that are very similar within the range may diverge considerably outside".

In most literature, the purposive selection of trees, even if not clearly detailed, involves partitioning the ranges of predictor variables by size classes. For example, Cunia and Briggs (1984) generally suggest considering "a representative sample of trees", while the case study refers to "29 sugar maple trees selected from a specific location in Vermont by stratified sampling, where the strata were defined as functions of the tree size"; Parresol (1999) generally speaks of trees "chosen through an appropriate selection procedure", while the case study refers to 39 willow oaks (*Quercus phellas* L.) selected "from 10 bottom-land hardwood stands in Mississipi"; more recently, Carvalho & Parresol (2003) perform the fitting of Pyrenean oaks (*Quercus pyrenaica* Willd.) phytomass on the basis of 163 trees cut from 83 plots from stands including "different ages and stocking levels to consider a wide range of tree dimensions".

When determining the number of trees to select in each class, it is worth noting that since tree stands over an area often exhibit large proportions of small trees, if the number is determined proportionally to the class sizes, the resulting set of trees will have a lot of small trees and generally few large trees, which may give insufficient information about the relationship on the upper ranges of the predictor variables. On the other hand, as pointed out in sub-section 2.2, phytomass (in terms of both commercial volume and fresh or dry weight) constitutes an highly heteroskedastic variable whose variability increases more than proportionally as tree dimension increases, so that elementary statistical considerations suggest the opposite strategy of observing more trees in the higher dimensional classes. In this framework, a compromise procedure is to choose a constant number of trees in all dimensional classes (see *e.g.* Ouellet 1983).

On the basis of these considerations, the tree selection procedures adopted in the EFOMI project did not follow a rigid probabilistic sampling scheme. Rather, most of the selected trees were chosen by means of several silvicultural practices, such as tending fellings and cuttings during road construction, while the remaining trees were purposively selected within the dimensional classes lacking an adequate number of trees. By means of this selection strategy the same number of trees was roughly obtained for all the diameter and height classes. Table 2 reports the numbers of selected trees by forest district and species or species group, while table 3 reports the number of selected trees by diameter class and species or species group.

At the end of this section it must also be noted that a separate collection of data could be performed for each component of the trees (wood, bark, foliage) in order to estimate the carbon content in each component. However, this procedure would have significantly reduced the number of sample trees owing to the length of time involved. Accordingly, a survey focused on collecting as many trees as possible was preferred in order to achieve accurate prediction equations mainly for the total above-ground phytomass and subsequently obtain carbon content estimates for the tree components by means of multiplicative coefficients available in literature.

2.5. *Field and laboratory measurements*

With reference to the measurements of predictor

Tab. 2 - Number of selected trees by forest districts and species or species group.
Tab. 2 - Numero di osservazioni per distretto forestale e specie o gruppi di specie.

	Forest district							
	Borgo Valsugana	Malè	Pergine	Riva del Garda	Rovereto	Tione	Trento	Total
Picea abies	11	15	8	2	-	34	12	82
Abies alba	13	-	13	2	-	12	-	40
Larix decidua	-	-	-	1	-	12	20	33
Pinus sylvestris	14	-	-	6	-	4	6	30
Pinus nigra	14	-	-	12	-	-	4	30
Pinus cembra	-	-	24	-	-	-	6	30
Fagus sylvatica	11	-	-	11	5	-	3	30
Ostrya carpinifolia	-	-	-	6	-	-	3	9
Quercus ilex	-	-	-	15	-	-	-	15
Quercus pubescens	1	-	-	5	-	-	-	6
Fraxinus sp.	1	-	-	9	-	-	-	10
Castanea sativa	-	-	-	9	-	-	4	13
Acer sp.	-	-	-	2	-	-	1	3
Salix sp.	-	-	-	5	-	-	1	6
Other hardwoods	-	-	-	4	-	-	2	6
Total	65	15	45	89	5	62	62	343

Tab. 3 - Number of selected trees by diameter classes and species or species group.
Tab. 3 - Numero di osservazioni per classe diametrica e specie o gruppi di specie.

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
Picea abies	11	16	16	15	24
Abies alba	8	13	3	7	9
Larix decidua	4	12	6	5	6
Pinus sylvestris	6	13	5	6	-
Pinus nigra	5	11	11	3	-
Pinus cembra	4	9	6	3	8
Fagus sylvatica	4	10	8	4	4
Ostrya carpinifolia	1	5	3	-	-
Quercus ilex	9	6	-	-	-
Quercus pubescens	4	2	-	-	-
Fraxinus sp.	8	2	-	-	-
Castanea sativa	3	7	1	2	-
Acer sp.	3	-	-	-	-
Salix sp.	2	4	-	-	-
Other hardwoods	5	-	1	-	-
Total	77	110	60	45	51

variables on the selected trees, the following procedure was performed: prior to felling, only the stem diameter outside the bark at breast height was measured; once the tree was felled, the diameter of the tree at the cut section, together with the stump height, the stem height from the cut section to the top and the length from the cut section to the crown insertion on the bole were measured. Diameters were measured with reference to two right-angled directions and expressed in centimetres with a millimetre approximation, while heights were expressed in metres with a centimetre approximation, except for the stump height, which was in centimetres.

As to the quantification of the phytomass components, a mixed geometric-ponderal survey was performed in order to reduce the high cost of direct measurements. More precisely, for the stem and branch portions with a minimum diameter of 5 cm, the diameters at the two ends and the distance between them were considered. Diameters were measured outside the bark with reference to two right-angle directions and expressed in centimetres with a millimetre approximation. The same standards were used for distances between the two diameters. For logs or branches with shapes differing from a truncated cone, the fresh weight in kilograms was measured with a ten-gram approximation. On the other hand, slightly more complex procedures were necessary to quantify the green parts of the bole and branches with a maximum diameter of 5 cm. The material was partitioned into an initial portion comprising the top of the stem and all the twigs with a basal diameter ranging from 3 to 5 cm, a second portion of twigs with a basal diameter ranging from 1 to 3 cm and a third portion of twigs with a basal diameter less than 1 cm. The dead portions of the crown of any size were also considered in another group. Finally the total fresh weight was measured in kilograms, with a ten-gram approximation, for each of these groups.

Subsequently, in order to quantify volumes and dry weights, samples (not in a statistical sense) from the several components of the trees were collected. More precisely:

- three wheels, or parts of wheels were withdrawn from the bole portions with a minimum diameter of 5 cm; the first wheel was taken from the basal end, the second from the mid-stem region and the third from the top;
- three portions of branches with an approximate regular shape were selected from branches with a minimum diameter of 5 cm;
- samples of branches including leaves, flowers and fruits were taken from each of the three above-mentioned groups partitioning the green branches with a basal diameter smaller than 5 cm;
- a single sample was finally taken from the dead portions of the crown.

In order to facilitate the subsequent laboratory quantification of volume and dry weights, all the collected samples were chosen to weigh from 2 to 3 kg. Then, the volumes of the stem and branch samples, expressed in cubic centimetres, were determined in the laboratory simply as the difference between the volumes of the liquid with and without the wood sample, while the dry weights for all the collected samples, expressed in kilograms with a gram approximation, were obtained by oven-drying and weighing each of these samples.

At the end of the field and laboratory procedures, the following quantities were available for each tree:

- the volume of the stem and branches with a minimum diameter of 5 cm;
- the stump volume, obtained by means of the mean diameter at cut sections and stump height;
- the fresh weight of the stem and branches, obtained by multiplying their volume by the mean ratio of fresh weight to the volume of bole and branch samples;
- the slash fresh weight;
- the mean ratio of dry weight to fresh weight for any sample of stem, branches, slash and dead portions;
- the dry weight of the stem and branches, slash and dead portions obtained by multiplying their fresh weight by the corresponding mean ratio of dry weight to fresh weight;
- the dry weight of the stump, obtained by multiplying its estimated volume by the mean ratio of dry weight to the stem volume.

Finally, by means of simple additions, it was possible to determine for each tree the dry weight of the cut wood (stem, branches, slash and dead portions), the above-ground dry weight for the whole tree (stem, branches, slash, dead portions and stump) and the total tree height, which was obtained by adding the stump height to the felled tree height, which, in turn, was measured by the distance from the cut section to the top of the crown.

Tables 4, 5 and 6 report the minimum, mean and maximum values of all these quantities by species and species groups, together with the number of felled trees for any species or species group. Moreover, the mean value and the coefficient of variation of some ratios usually adopted to estimate the total above-ground tree phytomass by means of the inventory values of timber volume are reported by species or species group. More precisely, the following ratios are considered:

- the ratio of fresh weight to volume for stem and branch samples (Tab. 7);
- the ratio of dry weight to volume for stem and branch samples (Tab. 8);
- the ratio of dry weight to fresh weight for stem and branch samples (Tab. 9);
- the ratio of dry weight to fresh weight for slash samples and the ratio of dry weight to the weight

measured in the field for dead portions (Tab. 10);
- the ratio of total above-ground fresh weight to stem and branch volume and the ratio of total above-ground dry weight to stem and branch volume (Tab. 11).

Finally, for each species and species group, the number of felled trees as well as the mean values for volume and phytomass components are reported by diameter classes from table 12 to table 20.

Tab. 4 - Minimum, mean and maximum values of size characteristics and phytomass components recorded on the selected trees of the species *Picea abies, Abies alba* and *Larix decidua*.
Tab. 4 - Valori minimi, medi e massimi delle principali grandezze rilevate sugli alberi campione delle specie Picea abies, Abies alba *e* Larix decidua.

	Picea abies (n= 82)			*Abies alba* (n= 40)			*Larix decidua* (n= 33)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
d	7.9	31.2	61.0	8.9	27.3	55.5	7.7	26.1	53.9
h	2.8	22.7	35.8	7.5	16.9	26.8	5.6	16.6	24.9
Stem V	17.8	1 222.3	4 067.0	26.9	788.7	2 697.5	23.4	579.0	1 882.6
Branch V	0.0	1.4	73.8	0.0	17.9	395.1	0.0	5.7	71.6
Stump V	0.5	31.7	132.2	0.3	23.9	200.6	1.6	12.1	35.8
Stem FW	11.2	1 061.0	3 657.0	29.0	725.1	2 366.5	20.5	493.8	1 613.9
Branch FW	0.0	1.2	62.2	0.0	21.4	474.5	0.0	5.8	74.3
Slash FW	6.4	226.2	875.6	5.5	216.9	773.8	4.4	88.2	219.2
Dead FW	0.0	15.2	97.2	0.0	12.0	94.8	0.0	6.8	53.3
Stem DW	7.0	467.5	1 608.5	10.7	301.1	973.0	0.8	258.2	936.1
Branch DW	0.0	0.8	39.2	0.0	9.7	203.6	0.0	3.4	45.9
Slash DW	2.5	116.1	485.4	2.7	105.1	370.0	2.1	43.8	118.0
Dead DW	0.0	11.8	77.7	0.0	8.3	59.3	0.0	5.4	43.1
Stump DW	0.2	12.0	53.6	0.1	9.1	79.6	0.7	5.7	17.0
Cut DW	10.3	596.1	2 083.9	19.7	424.2	1 343.0	10.7	310.9	1 048.8
AG DW	10.5	608.1	2 124.8	19.8	433.4	1 387.0	18.6	316.5	1 058.0

Tab. 5 - Minimum, mean and maximum values of size characteristics and phytomass components recorded on the selected trees of *Pinus* species.
Tab. 5 - Valori minimi, medi e massimi delle principali grandezze rilevate sugli alberi campione delle specie del genere Pinus.

	Pinus sylvestris (n= 30)			*Pinus nigra* (n= 30)			*Pinus cembra* (n= 30)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
d	8.4	21.3	40.6	8.9	22.4	35.9	7.7	28.8	56.3
h	6.4	12.6	20.8	5.6	12.2	20.9	4.5	14.2	22.2
Stem V	24.6	304.2	1 253.5	20.6	315.0	896.7	13.2	725.0	2 609.9
Branch V	0.0	14.9	112.3	0.0	11.5	63.6	0.0	3.2	26.9
Stump V	0.4	5.0	22.1	0.6	6.1	16.4	0.2	19.7	74.2
Stem FW	19.8	272.3	1 208.1	15.7	290.3	880.0	10.5	519.0	1 732.6
Branch FW	0.0	14.6	107.2	0.0	11.5	65.9	0.0	2.8	25.0
Slash FW	7.7	66.5	264.1	4.2	106.9	313.4	4.7	95.9	372.3
Dead FW	0.0	7.9	59.0	0.4	7.7	37.5	0.0	21.8	100.5
Stem DW	9.6	134.6	600.6	9.0	148.1	396.1	5.0	276.1	930.1
Branch DW	0.0	7.2	51.8	0.0	6.2	33.8	0.0	1.7	16.7
Slash DW	3.8	30.6	123.1	1.8	54.4	152.9	2.5	48.9	209.1
Dead DW	0.0	6.2	51.3	0.0	6.2	29.8	0.0	17.5	83.9
Stump DW	0.2	2.2	8.3	0.3	2.8	8.6	0.1	7.6	31.0
Cut DW	13.9	178.6	728.2	14.8	215.0	596.6	8.4	344.2	1 233.4
AG DW	14.1	180.8	735.1	15.1	217.8	603.4	8.5	351.8	1 247.1

Tab. 6 - Minimum, mean and maximum values of size characteristics and phytomass components recorded on the selected hardwoods trees.
Tab. 6 - Valori minimi, medi e massimi delle principali grandezze rilevate sugli alberi campione di latifoglie.

	Fagus sylvatica (n = 30)			*Ostrya carpinifolia* and other similar tree species (n = 40)			*Castanea sativa* and other similar tree species (n = 28)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
d	9.5	26.3	56.5	5.1	12.4	31.6	6.7	15.6	38.4
h	9.3	16.3	22.3	5.5	10.2	17.7	5.8	11.3	21.7
Stem V	44.1	463.2	1 223.0	3.4	97.9	577.0	10.5	146.4	913.6
Branch V	0.0	132.1	1 243.3	0.0	9.3	120.9	0.0	12.1	113.9
Stump V	0.7	25.0	134.0	0.1	3.0	24.1	0.2	10.9	75.1
Stem FW	44.3	488.4	1 363.0	3.3	106.0	619.8	10.9	133.1	814.0
Branch FW	0.0	145.1	1 409.0	0.0	9.8	126.5	0.0	11.6	104.1
Slash FW	6.3	200.7	1 203.1	2.3	37.3	174.0	6.2	51.7	242.3
Dead FW	0.0	6.2	74.3	0.0	0.6	3.3	0.0	2.5	14.3
Stem DW	24.9	272.4	743.1	2.2	64.4	351.2	6.3	69.2	403.0
Branch DW	0.0	78.9	741.7	0.0	6.1	80.2	0.0	6.2	54.3
Slash DW	5.8	107.2	659.6	1.3	20.8	99.6	2.7	26.1	123.5
Dead DW	0.0	4.7	55.9	0.0	0.5	2.5	0.0	1.9	11.7
Stump DW	0.4	14.7	80.5	0.1	2.0	14.5	0.1	5.1	33.1
Cut DW	30.7	463.2	1 908.8	6.4	91.8	454.6	12.5	103.3	587.7
AG DW	31.1	477.9	1 927.2	6.6	93.9	462.4	12.8	108.4	620.8

Tab. 7 - Mean values and coefficients of variation of the ratios FW/V for the stem and branches by species or group of species.
Tab. 7 - Valori medi e coefficienti di variazione dei rapporti FW/V relativi al fusto e rami grossi per le diverse specie o gruppi di specie.

Species	Stem FW / V (kg dm^{-3})			Branch FW / V (kg dm^{-3})		
	n	Mean	CV	n	Mean	CV
Picea abies	82	0.87	8.5	5	0.95	9.8
Abies alba	40	0.95	7.7	5	1.14	6.8
Larix decidua	33	0.86	4.7	9	0.98	4.6
Pinus sylvestris	30	0.90	6.0	14	0.98	5.3
Pinus nigra	30	0.89	8.3	13	1.00	5.2
Pinus cembra	30	0.72	8.9	9	0.86	7.3
Fagus sylvatica	30	1.06	4.4	17	1.09	3.4
Ostrya carpinifolia	9	1.05	2.9	3	1.05	2.3
Quercus ilex	15	1.19	2.3	2	1.19	1.7
Quercus pubescens	6	1.02	5.5	2	1.06	5.0
Fraxinus sp.	10	0.98	5.4	1	0.99	-
Castanea sativa	13	0.92	6.1	6	0.99	12.7
Acer sp.	3	0.97	10.4	-	-	-
Salix sp.	6	0.89	6.0	1	0.84	-
Other hardwoods	6	0.95	9.5	1	0.98	-

Tab. 8 - Mean values and coefficients of variation of the ratios DW/V for the stem and branches by species or group of species.
Tab. 8 - Valori medi e coefficienti di variazione dei rapporti DW/V relativi al fusto e rami grossi per le diverse specie o gruppi di specie.

Species	Stem DW / V (kg dm^{-3})			Branch DW / V (kg dm^{-3})		
	n	Mean	CV	n	Mean	CV
Picea abies	82	0.39	8.3	5	0.61	16.8
Abies alba	40	0.39	7.6	5	0.61	13.6
Larix decidua	33	0.46	8.7	9	0.58	6.9
Pinus sylvestris	30	0.44	8.9	14	0.49	7.2
Pinus nigra	30	0.47	7.9	13	0.56	8.7
Pinus cembra	30	0.39	5.9	9	0.53	13.5
Fagus sylvatica	30	0.60	6.6	17	0.62	12.9
Ostrya carpinifolia	9	0.65	9.9	3	0.61	4.9
Quercus ilex	15	0.75	2.6	2	0.72	2.5
Quercus pubescens	6	0.61	3.3	2	0.66	6.8
Fraxinus sp.	10	0.62	6.1	1	0.65	-
Castanea sativa	13	0.57	19.6	6	0.55	10.7
Acer sp.	3	0.55	16.6	-	-	-
Salix sp.	6	0.45	1.4	1	0.47	-
Other hardwoods	6	0.51	15.0	1	0.52	-

Tab. 9 - Mean values and coefficients of variation of the ratios DW/FW for the stem and branches by species or group of species.
Tab. 9 - Valori medi e coefficienti di variazione dei rapporti DW/FW relativi al fusto e rami grossi per le diverse specie o gruppi di specie.

Species	Stem DW / FW			Branch DW / FW		
	n	Mean	CV	n	Mean	CV
Picea abies	82	0.46	11.6	5	0.64	11.2
Abies alba	40	0.41	9.7	6	0.49	22.1
Larix decidua	33	0.54	10.0	9	0.59	4.4
Pinus sylvestris	30	0.49	9.1	14	0.51	8.8
Pinus nigra	30	0.53	9.0	13	0.56	7.9
Pinus cembra	30	0.55	8.8	9	0.61	10.2
Fagus sylvatica	30	0.56	6.3	17	0.57	12.1
Ostrya carpinifolia	9	0.62	11.5	3	0.58	4.5
Quercus ilex	15	0.63	2.8	2	0.61	4.2
Quercus pubescens	6	0.60	2.9	2	0.63	11.6
Fraxinus sp.	10	0.63	2.2	1	0.66	-
Castanea sativa	13	0.56	11.8	6	0.57	16.2
Acer sp.	3	0.57	6.9	-	-	-
Salix sp.	6	0.51	5.9	1	0.56	-
Other hardwoods	6	0.53	7.7	1	0.53	-

Tab. 10 - Mean values and coefficients of variation of the ratios DW/FW for slash and dead crown portions by species or group of species.
Tab. 10 - Valori medi e coefficienti di variazione dei rapporti DW/FW relativi alla ramaglia e ai rami morti per le diverse specie o gruppi di specie.

Species	Slash DW / FW			Dead branch DW / FW		
	n	Mean	CV	n	Mean	CV
Picea abies	82	0.49	16.5	82	0.76	11.6
Abies alba	40	0.47	7.9	33	0.72	14.9
Larix decidua	33	0.49	5.5	25	0.77	6.0
Pinus sylvestris	30	0.46	6.8	29	0.76	22.2
Pinus nigra	30	0.52	8.3	29	0.79	10.5
Pinus cembra	30	0.50	7.5	26	0.78	8.9
Fagus sylvatica	30	0.55	18.3	13	0.73	9.1
Ostrya carpinifolia	9	0.54	8.9	4	0.77	8.2
Quercus ilex	15	0.57	4.7	10	0.82	23.2
Quercus pubescens	6	0.57	5.3	5	0.73	17.6
Fraxinus sp.	10	0.56	5.3	2	0.72	25.4
Castanea sativa	13	0.53	11.1	11	0.79	10.5
Acer sp.	3	0.47	17.8	-	-	-
Salix sp.	6	0.46	6.9	4	0.73	1.8
Other hardwoods	6	0.51	6.6	4	0.62	15.1

Tab. 11 - Mean values and coefficients of variation of the ratios FW(whole tree)/V(stem and branches) and DW(whole tree)/V(stem and branches) by species or group of species.
Tab. 11 - Valori medi e coefficienti di variazione dei rapporti FW(intero albero)/V(fusto e rami grossi) e DW(intero albero)/V(fusto e rami grossi) per le diverse specie o gruppi di specie.

Species	FW tot / Stem + Branch V (kg dm^{-3})			DW tot / Stem + Branch V (kg dm^{-3})		
	n	Mean	CV	n	Mean	CV
Picea abies	82	1.13	26.8	82	0.52	22.2
Abies alba	40	1.35	18.8	40	0.57	16.6
Larix decidua	33	1.17	28.9	33	0.60	27.7
Pinus sylvestris	30	1.21	15.6	30	0.58	13.4
Pinus nigra	30	1.25	22.8	30	0.65	20.6
Pinus cembra	30	0.90	20.2	30	0.47	14.4
Fagus sylvatica	30	1.61	24.3	30	0.89	23.5
Ostrya carpinifolia	9	1.41	10.5	9	0.85	10.6
Quercus ilex	15	1.99	34.7	15	1.20	30.9
Quercus pubescens	6	1.54	17.0	6	0.92	17.5
Fraxinus sp.	10	1.93	34.0	10	1.17	33.6
Castanea sativa	13	1.31	16.7	13	0.73	18.2
Acer sp.	3	2.04	9.7	3	1.06	20.0
Salix sp.	6	1.78	17.5	6	0.87	15.5
Other hardwoods	6	1.50	14.9	6	0.79	18.2

Tab. 12 - Mean values of the phytomass components for the species *Picea abies* by diameter class.
Tab. 12 - Valori medi delle varie componenti della fitomassa rilevate sugli alberi campione della specie Picea abies *suddivisi per classe diametrica.*

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
n	11	16	16	15	24
Stem V + Branch V	40.7	211.9	771.5	1 403.6	2 629.3
Stem FW + Branch FW	36.3	172.2	673.3	1 239.9	2 274.0
Stem DW + Branch DW	17.6	85.9	304.0	538.2	995.5
Slash FW	17.5	39.5	122.2	230.9	512.7
Slash DW	7.2	20.2	58.2	117.2	267.8
Dead FW	1.4	3.5	9.2	15.6	33.1
Dead DW	1.0	2.7	7.3	12.8	25.2

Tab. 13 - Mean values of the phytomass components for the species *Abies alba* by diameter class.
Tab. 13 - Valori medi delle varie componenti della fitomassa rilevate sugli alberi campione della specie Abies alba *suddivisi per classe diametrica.*

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
n	8	13	3	7	9
Stem V + Branch V	38.7	169.6	783.9	1 203.9	2 107.7
Stem FW + Branch FW	36.5	162.4	757.9	1 142.6	1 909.6
Stem DW + Branch DW	15.6	63.6	311.7	466.3	809.1
Slash FW	19.7	68.2	195.0	351.9	509.1
Slash DW	9.0	30.8	95.1	171.4	249.8
Dead FW	1.5	2.9	3.3	5.1	42.9
Dead DW	1.6	2.1	2.5	3.4	29.1

Tab. 14 - Mean values of the phytomass components for the species *Larix decidua* by diameter class.
Tab. 14 - Valori medi delle varie componenti della fitomassa rilevate sugli alberi campione della specie Larix decidua *suddivisi per classe diametrica.*

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
n	4	12	6	5	6
Stem V + Branch V	43.3	153.3	409.2	1 027.3	1 614.8
Stem FW + Branch FW	35.2	133.2	360.7	861.8	1 379.1
Stem DW + Branch DW	19.3	71.0	192.4	504.8	670.9
Slash FW	16.3	44.3	115.9	144.1	150.0
Slash DW	7.7	20.8	58.7	72.4	75.4
Dead FW	0.6	2.4	8.6	9.4	15.7
Dead DW	0.4	1.8	7.0	7.4	12.6

Tab. 15 - Mean values of the phytomass components for the species *Pinus sylvestris* by diameter class.
Tab. 15 - Valori medi delle varie componenti della fitomassa rilevate sugli alberi campione della specie Pinus sylvestris *suddivisi per classe diametrica.*

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
n	6	13	5	6	-
Stem V + Branch V	45.5	145.3	517.2	804.3	-
Stem FW + Branch FW	40.0	135.5	456.7	719.8	-
Stem DW + Branch DW	19.5	66.0	222.8	361.2	-
Slash FW	12.5	42.3	84.7	157.7	-
Slash DW	5.9	18.9	39.8	72.7	-
Dead FW	1.0	3.2	6.6	26.0	-
Dead DW	0.6	2.3	4.3	21.7	-

Tab. 16 - Mean values of the phytomass components for the species *Pinus nigra* by diameter class.
Tab. 16 - Valori medi delle varie componenti della fitomassa rilevate sugli alberi campione della specie Pinus nigra *suddivisi per classe diametrica.*

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
n	5	11	11	3	-
Stem V + Branch V	40.1	128.3	540.0	747.5	-
Stem FW + Branch FW	32.2	115.4	509.7	672.0	-
Stem DW + Branch DW	18.3	59.2	261.3	337.5	-
Slash FW	4.7	47.6	193.3	178.2	-
Slash DW	2.3	24.8	97.8	91.1	-
Dead FW	0.6	2.9	11.7	22.1	-
Dead DW	0.9	2.2	9.4	18.2	-

Tab. 17 - Mean values of the phytomass components for the species *Pinus cembra* by diameter class.
Tab. 17 - Valori medi delle varie componenti della fitomassa rilevate sugli alberi campione della specie Pinus cembra *suddivisi per classe diametrica.*

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
n	4	9	6	3	8
Stem V + Branch V	19.3	148.1	511.1	935.5	1 820.5
Stem FW + Branch FW	15.1	105.3	348.3	672.4	1 317.3
Stem DW + Branch DW	8.1	56.0	201.0	352.3	691.8
Slash FW	6.7	20.6	46.6	100.6	260.3
Slash DW	3.0	10.2	23.5	51.1	133.6
Dead FW	0.4	5.0	15.5	15.7	58.2
Dead DW	0.3	3.7	12.3	12.4	47.2

Tab. 18 - Mean values of the phytomass components for the species *Fagus sylvatica* by diameter class.
Tab. 18 - Valori medi delle varie componenti della fitomassa rilevate sugli alberi campione della specie Fagus sylvatica *suddivisi per classe diametrica.*

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
n	4	10	8	4	4
Stem V + Branch V	63.4	197.5	592.3	1 068.0	1 655.2
Stem FW + Branch FW	68.3	210.1	633.2	1 124.8	1 766.6
Stem DW + Branch DW	37.2	122.2	347.5	621.9	975.3
Slash FW	15.0	59.5	164.3	356.7	656.2
Slash DW	8.5	27.9	90.1	187.4	358.5
Dead FW	0.4	0.7	5.4	20.0	13.8
Dead DW	0.2	0.5	4.1	15.1	10.3

Tab. 19 - Mean values of the phytomass components for the group *Ostrya carpinifolia* and other similar tree species by diameter class.
Tab. 19 - Valori medi delle varie componenti della fitomassa rilevate sugli alberi campione del gruppo Ostrya carpinifolia *e altre specie simili suddivisi per classe diametrica.*

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
n	22	14	4	-	-
Stem V + Branch V	20.6	130.4	502.7	-	-
Stem FW + Branch FW	22.4	145.4	525.8	-	-
Stem DW + Branch DW	13.9	92.5	305.2	-	-
Slash FW	12.2	54.2	116.4	-	-
Slash DW	6.8	30.4	64.4	-	-
Dead FW	0.3	0.8	1.5	-	-
Dead DW	0.3	0.6	1.1	-	-

Tab. 20 - Mean values of the phytomass components for the group *Castanea sativa* and other similar tree species by diameter class.
Tab. 20 - Valori medi delle varie componenti della fitomassa rilevate sugli alberi campione del gruppo Castanea sativa *e altre specie simili suddivisi per classe diametrica.*

	Diameter classes (cm)				
	d<12.5	12.5≤d<22.5	22.5≤d<32.5	32.5≤d<42.5	d≥42.5
n	13	11	2	2	-
Stem V + Branch V	30.3	132.6	409.7	881.5	-
Stem FW + Branch FW	28.6	120.3	367.2	811.4	-
Stem DW + Branch DW	16.0	66.1	195.0	392.6	-
Slash FW	20.1	51.0	132.1	181.4	-
Slash DW	9.6	26.8	64.1	91.1	-
Dead FW	0.4	2.8	5.1	11.3	-
Dead DW	0.3	2.1	4.0	9.3	-

2.6. Parameter estimation

In order to perform the estimation of parameters **B** and **Σ** on model (3), denote by $\mathbf{x}_i$ and $\mathbf{y}_i$ (i= 1,2,...,n) the **x**- and **y**-vectors recorded on n trees purposively selected as to be representative of both the diameter and height ranges. Then, denote by **X** the nxl matrix having $\mathbf{x}_i^T$ in the i-th row and by **Y** the nx4 matrix having $\mathbf{y}_i^T$ in the i-th row. It is worth noting that, owing to the purposive selection of trees, the matrix **X** turns out to be nonstochastic, as usually happens in standard least square procedures. Accordingly, the least-square estimates of **B** and **Σ** are respectively given by (see *e.g.* Rencher 1998: section 7.4)

$$\hat{\mathbf{B}} = (\mathbf{X}^T \mathbf{X})^{-1} \mathbf{X}^T \mathbf{Y}$$

and

$$\mathbf{S} = \frac{1}{n-l} (\mathbf{Y} - \mathbf{X}\hat{\mathbf{B}})^T (\mathbf{Y} - \mathbf{X}\hat{\mathbf{B}})$$

Moreover, the estimated standard error for $\hat{b}_{jk}$ (j= 1, ..., l ; k= 1, ..., 4) is given by

$$se(\hat{b}_{jk}) = s_k \sqrt{g_{jj}}$$

where g_{jj} is the jj-element of $(\mathbf{X}^T \mathbf{X})^{-1}$ while s_k^2 is the kk-element of **S**. Obviously, being $\mathbf{b} = \mathbf{Bl}$ and $\sigma_w^2 = \mathbf{1}^T \mathbf{\Sigma l}$, the least-squares estimates of these parameters become $\hat{\mathbf{b}} = \hat{\mathbf{B}}\mathbf{l}$ and $s_w^2 = \mathbf{1}^T \mathbf{Sl}$, while the estimated standard error for $\hat{b}_j$ (j= 1, ..., l) is given by

$$se(\hat{b}_j) = s_w \sqrt{g_{jj}}$$

As to the prediction of the phytomass components for a tree with diameter d_0 and height h_0, denote by $\mathbf{u}_0^T = [u_{01}, ..., u_{0l}]$ the l-vector, where u_{01}= 1 and u_{02}, ..., u_{0l} are the combinations of d_0 and/or h_0 adopted in model (1). Thus, in accordance with the previous results, the biomass prediction for the four components of the tree is given by

$$\mathbf{w}^T = \mathbf{u}_0^T \hat{\mathbf{B}} \tag{7}$$

while the sum of the estimates for each phytomass component, say

$$w_0 = \hat{\mathbf{w}}_0^T \mathbf{l} \tag{8}$$

obviously constitutes the prediction for the total biomass. Moreover, the estimated standard error for the prediction $\hat{w}_{0k}$ of the k-th component (k= 1, ..., 4) becomes

$$se(\hat{w}_{0k}) = s_k \sqrt{\mathbf{u}_0^T (\mathbf{X}^T\mathbf{X})^{-1} \mathbf{u}_o} \tag{9}$$

while the estimated standard error for the whole biomass prediction is given by

$$se(\hat{w}_0) = s_w \sqrt{\mathbf{u}_0^T (\mathbf{X}^T\mathbf{X})^{-1} \mathbf{u}_o} \tag{10}$$

Repeating the procedure for several vectors $\mathbf{u}_o$, biomass tables may be constructed that ensure consistent predictions of the phytomass components with respect to the prediction of the total phytomass.

It is worth noting that the estimation procedure described in this section is referred to as Method 2 by Cunia and Briggs (1984) who also consider two alternative procedures that satisfy the additivity condition. The procedure referred to as the Method 1 views model (1) as a sequence of four different models for each component, whose parameters are estimated separately, in such a way that additivity is simply ensured by estimating total phytomass as the sum of each component estimate. As concerns this method, the authors point out that "even if not necessary, it is customary to assume that the regression functions are all linear, they are calculated by the least squares method and that in a given regression only those independent variables x are included that are statistically significant". Notwithstanding this, Cunia and Briggs claim that "no statements about the reliability of the total biomass table can be easily derived". Hence, the authors propose a third procedure, referred to as Method 3 which, once again, makes use of only those variables which turned out to be statistically significant in the single component regressions. The appeal of Method 3 with respect to Method 1 is that the variances of the total phytomass predictions can be estimated. However, it is at once apparent that if a variance-covariance structure of type (2) is supposed, then there is no need to introduce Method 3, since the variance estimates of the total phytomass predictions in Method 1 may be straightforwardly obtained in the familiar framework of constrained least-squares procedures. Finally, Cunia and Briggs (1984) emphasize that Method 2, by making use of non-significant regressors, turns out to be less precise than Method 1 and 3. Through a practical example, the authors show that the confidence intervals arising from Method 2 are wider than those provided by the other methods. However, it is worth noting that the regressor choice adopted in methods 1 and 3 is performed by means of statistical tests, and as such, it constitutes a random choice which necessarily entails some sampling variability. Hence, the variance estimates adopted for these methods neglect a source of variability which may also be relevant. Thus, in accordance with these considerations, Method 2 seems to be the most reliable, at least from a theoretical point of view. On the other hand, more investigation is needed into the properties of methods 1 and 3, perhaps within the recent context of considering model selection as an integral part of statistical inference (see *e.g.* Burnham & Anderson 1998).

Finally, as to the estimation of the parameters **c** and σ_v^2 of model (6), from the very straightforward application of ordinary least-squares in multiple linear regression models, it follows that

$$\hat{\mathbf{c}} = (\mathbf{X}^T\mathbf{X})^{-1}\,\mathbf{X}^T\mathbf{z}$$

and

$$s_v^2 = \frac{1}{n\text{-}2}\,(\mathbf{z}\text{-}\mathbf{X}\hat{\mathbf{c}})^T\,(\mathbf{z}\text{-}\mathbf{X}\hat{\mathbf{c}})$$

where z_i (i= 1,2,...,n) represent the z-values recorded on n trees and **z** denotes the n vector having z_i as the i-th element. Moreover, the estimated standard error for c_j (j= 1,2) is given by

$$se(\hat{c}_j)= s_v\sqrt{g_{jj}}$$

where, once again, g_{jj} is the jj-element of $(\mathbf{X}^T\mathbf{X})^{-1}$. Finally, the prediction of the stem and branch volume for a tree with diameter d_0 and height h_0, turns out to be

(11) $$\hat{v}_0= \mathbf{u}_0^T\,\hat{\mathbf{c}}$$

with an estimated standard error of

(12) $$se(v_0)= s_v\sqrt{\mathbf{u}_0^T(\mathbf{X}^T\mathbf{X})^{-1}\,\mathbf{u}_o}$$

2.7. *Results*

The estimation techniques described in sub-section 2.6 were applied to the data collected and measured in accordance with the procedures presented in sub-section 2.5. Then, for each species or group of species, the following results were reported (Tabs 21-38 and Figs 1-36):

i) the table showing the frequencies of the selected trees by diameter and height classes;
ii) the table showing the structure of the resulting prediction equation together with the coefficient estimates and the corresponding standard errors; sometimes, for combinations of small d and h values the prediction equations may give rise to negative values; in these cases predictions are set zero and they are neglected in the subsequent computation of the total phytomass;
iii) the scatter plot of observed and fitted values for the stem and branch volume *vs* d^2h;
iv) the scatter plot of residuals for the stem and branch volume *vs* fitted values;
v) the scatter plot of observed and fitted values for the whole tree phytomass *vs* d^2h;
vi) the scatter plot of residuals for the whole tree phytomass *vs* fitted values.

3. TWO CASE STUDIES IN INTENSIVE MONITORING AREAS

To illustrate the effectiveness of the model-based procedures described in section 2 in the ongoing assessment of forest stands, the equations reported in sub-section 2.7 were adopted to predict the volume and the phytomass for the areas of Lavazè Pass and Pomarolo in the Province of Trento. The intensive monitoring of these areas is one aim of the EFOMI project and both areas have been described in numerous reports concerning the project.

As to the area of Lavazè Pass, surveys were performed during winter 1996-97, 1999-2000 and 2004-2005 by the National Forestry Corps (CONECOFOR Service) as part of the National Intensive Monitoring Network of Forest Ecosystems Program (co-financed by the European Commission). In each survey, diameters values were recorded for all the trees in the area while height measurements were performed only for a purposively selected sample of trees. Therefore, height values not recorded in the field were predicted by means of the well-known Chapman and Richard non-linear equation which was fitted to the data by means of iterative procedures (Brandini *et al.* 1995). It is worth noting that, in order to gain initial insight into the standard error of the total volume and phytomass predictions in the Lavazè Pass area, the height predictions were supposed without errors, as if the heights had been recorded directly from the trees. Obviously, this assumption gave rise to an under-estimation of the actual standard errors. On the other hand, as to the Pomarolo area, a complete census of diameters and heights was performed during the winter of 2004-2005 in such a way that an unbiased estimate of the standard error for the total volume and phytomass predictions could be achieved.

Generally speaking, denote by $\mathbf{u}_1,...,\mathbf{u}_N$ the vector of predictor variables observed for each of the N trees of a given species in the monitoring area and denote by $p_1,...,p_N$ the predictions of a phytomass component, or total phytomass or volume for each single tree, which may be obtained by means of expressions (7), (8) or (11), respectively. Thus, by straightforward statistical considerations, an unbiased predictor over the whole study area is given by

$$\hat{T}= \sum_{i=1}^{N} p_i$$

with a model-based variance which can be unbiasedly estimated by

$$\hat{V}(\hat{T})= \sum_{i=1}^{N} V_i^2 + 2\sum_{j>i=1}^{N} V_{ij}$$

where V_i^2 (i=1,...,N) is the estimate of the i-th prediction variance, obtained from the squares of the quantities (9), (10) or (12), respectively, while V_{ij} ($j>i$= 1,...,N) constitutes the estimate of the covariance between the predictions of trees i and j, which, up to the multiplicative factors s_k^2, s_w^2 or s_v^2 is given by the quantity $\mathbf{u}_i^T(\mathbf{X}^T\,\mathbf{X})^{-1}\,\mathbf{u}_j$. Obviously, the total phytomass over the whole area is straightforwardly predicted as the sum of the phytomass predictions for each species. Moreover, since the prediction equations of the species are usually

Tab. 21 - Frequencies of the selected trees for the species *Picea abies* by dimensional classes.
Tab. 21 - Frequenze degli alberi campione della specie Picea abies *per classi dimensionali.*

Diameter classes (cm)	Height classes (m)						
	h<10	10≤h<15	15≤h<20	20≤h<25	25≤h<30	h≥30	Total
d<12.5	7	4	-	-	-	-	11
12.5≤d<22.5	4	2	5	5	-	-	16
22.5≤d<32.5	-	-	3	9	3	1	16
32.5≤d<42.5	-	-	1	4	3	7	15
d≥42.5	-	-	-	2	9	13	24
Total	11	6	9	20	15	21	82

Tab. 22 - Coefficients and standard error estimates of the prediction equations for the species *Picea abies*.
Tab. 22 - Stime dei coefficienti e dei relativi errori standard nelle equazioni di previsione relative alla specie Picea abies*.*

Dependent variable	Model structure $b_1 + b_2d^2h + b_3dh^2$					
	$\hat{b}_1$	$se(\hat{b}_1)$	$\hat{b}_2$	$se(\hat{b}_2)$	$\hat{b}_3$	$se(\hat{b}_3)$
Stem + Branch V (V)	4.3766	0.7719	0.0285	0.0019	0.0117	0.0024
Stem + Branch DW (w1)	2.5338	$5.3510 \cdot 10^{-1}$	$9.5351 \cdot 10^{-3}$	$1.3180 \cdot 10^{-3}$	$6.2893 \cdot 10^{-3}$	$1.6547 \cdot 10^{-3}$
Slash DW (w2)	5.4653	$7.8494 \cdot 10^{-1}$	$8.1739 \cdot 10^{-3}$	$1.9335 \cdot 10^{-3}$	$-5.8838 \cdot 10^{-3}$	$2.4273 \cdot 10^{-3}$
Dead DW (w3)	$6.4730 \cdot 10^{-1}$	$8.6712 \cdot 10^{-2}$	$4.2878 \cdot 10^{-4}$	$2.1359 \cdot 10^{-4}$	$-1.0435 \cdot 10^{-4}$	$2.6814 \cdot 10^{-4}$
Stump DW (w4)	$1.8324 \cdot 10^{-1}$	$4.0442 \cdot 10^{-2}$	$6.2237 \cdot 10^{-4}$	$9.9617 \cdot 10^{-5}$	$-3.8640 \cdot 10^{-4}$	$1.2506 \cdot 10^{-4}$
AG DW (wtot)	8.8297	$8.5243 \cdot 10^{-1}$	$1.8760 \cdot 10^{-2}$	$2.0997 \cdot 10^{-3}$	$-8.5316 \cdot 10^{-5}$	$2.6360 \cdot 10^{-3}$

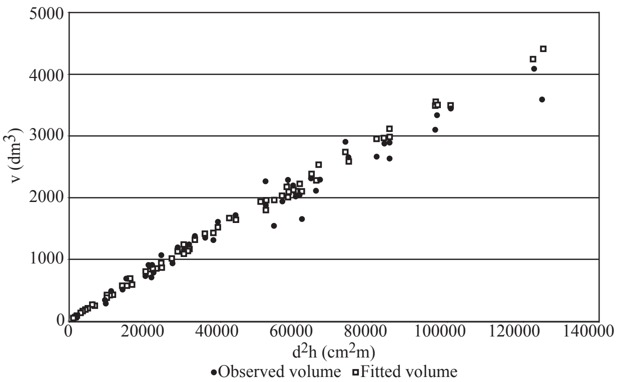

Fig. 1 - Observed and fitted values of stem and branch volume for the species *Picea abies*.
Fig. 1 - Rappresentazione grafica dei valori osservati e stimati del volume del fusto e rami grossi per la specie Picea abies.

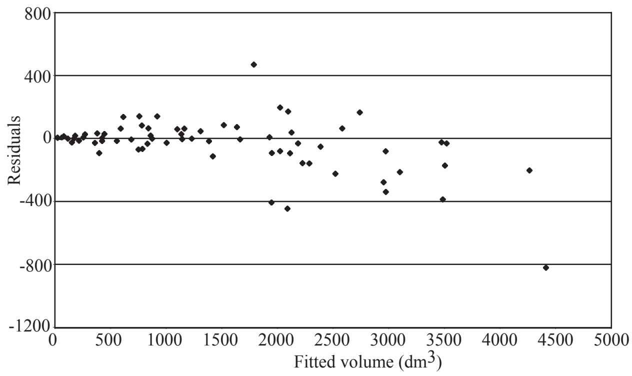

Fig. 2 - Residuals of the stem and branch volume regression for the species *Picea abies*.
Fig. 2 - Valori residui del volume del fusto e rami grossi per la specie Picea abies.

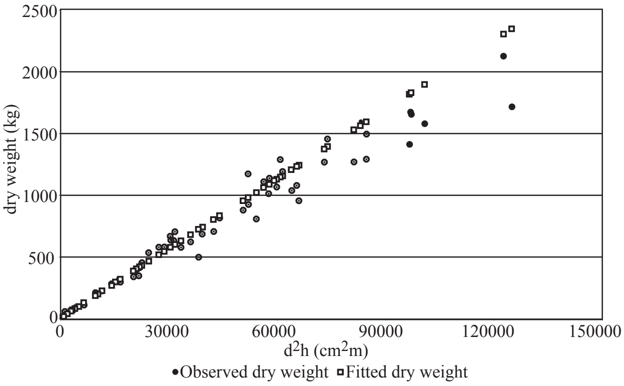

Fig. 3 - Observed and fitted values of the total dry weight for the species *Picea abies*.
Fig. 3 - Rappresentazione grafica dei valori osservati e stimati del peso secco totale del fusto e rami grossi per la specie Picea abies.

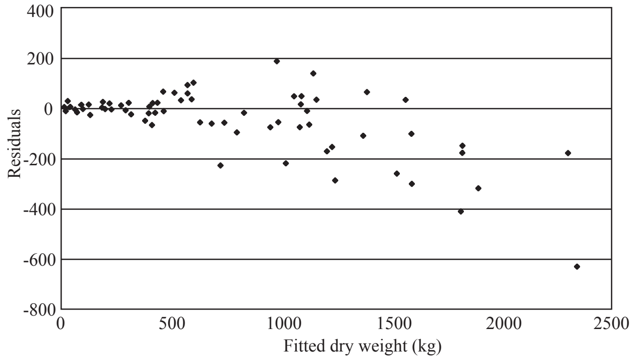

Fig. 4 - Residuals of the total dry weight regression for the species *Picea abies*.
Fig. 4 - Valori residui del peso secco totale del fusto e rami grossi per la specie Picea abies.

Tab. 23 - Frequencies of the selected trees for the species *Abies alba* by dimensional classes.
Tab. 23 - Frequenze degli alberi campione della specie Abies alba *per classi dimensionali.*

Diameter classes (cm)	Height classes (m)						
	h<10	10≤h<15	15≤h<20	20≤h<25	25≤h<30	h≥30	Total
d<12.5	7	1	-	-	-	-	8
12.5≤d<22.5	-	10	2	1	-	-	13
22.5≤d<32.5	-	-	-	3	-	-	3
32.5≤d<42.5	-	-	-	5	2	-	7
d≥42.5	-	-	-	7	2	-	9
Total	7	11	2	16	4	-	40

Tab. 24 - Coefficients and standard error estimates of the prediction equations for the species *Abies alba*.
Tab. 24 - Stime dei coefficienti e dei relativi errori standard nelle equazioni di previsione relative alla specie Abies alba.

Dependent variable	Model structure $b_1 + b_2 d^2 h + b_3 d^2$					
	$\hat{b}_1$	$se(\hat{b}_1)$	$\hat{b}_2$	$se(\hat{b}_2)$	$\hat{b}_3$	$se(\hat{b}_3)$
Stem + Branch V (V)	-2.7916	4.6520	$3.4492\cdot10^{-2}$	$3.3378\cdot10^{-3}$	$8.3540\cdot10^{-2}$	$6.6703\cdot10^{-2}$
Stem + Branch DW(w1)	$9.8961\cdot10^{-1}$	2.1423	$1.3980\cdot10^{-2}$	$1.5371\cdot10^{-3}$	$1.4895\cdot10^{-2}$	$3.0717\cdot10^{-2}$
Slash DW (w2)	1.6305	2.8543	$1.7321\cdot10^{-3}$	$2.0480\cdot10^{-3}$	$6.8361\cdot10^{-2}$	$4.0927\cdot10^{-2}$
Dead DW (w3)	$8.4530\cdot10^{-1}$	$5.7960\cdot10^{-1}$	$4.6052\cdot10^{-4}$	$4.1587\cdot10^{-4}$	$-3.1032\cdot10^{-3}$	$8.3106\cdot10^{-3}$
Stump DW (w4)	$-1.2302\cdot10^{-1}$	$2.8292\cdot10^{-1}$	$3.1463\cdot10^{-4}$	$2.0300\cdot10^{-4}$	$1.2020\cdot10^{-3}$	$4.0566\cdot10^{-3}$
AG DW (wtot)	3.3424	3.6804	$1.6487\cdot10^{-2}$	$2.6407\cdot10^{-3}$	$8.1355\cdot10^{-2}$	$5.2771\cdot10^{-2}$

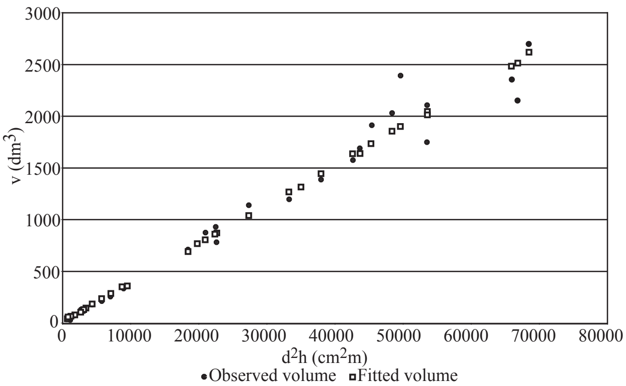

Fig. 5 - Observed and fitted values of stem and branch volume for the species *Abies alba*.
Fig. 5 - Rappresentazione grafica dei valori osservati e stimati del volume del fusto e rami grossi per la specie Abies alba.

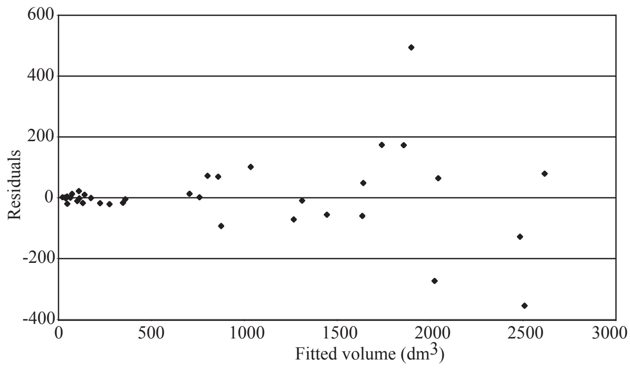

Fig. 6 - Residuals of stem and branch volume regression for the species *Abies alba*.
Fig. 6 - Valori residui del volume del fusto e rami grossi per la specie Abies alba.

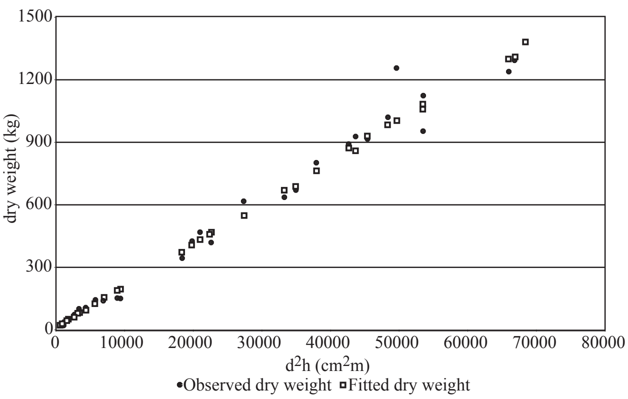

Fig. 7 - Observed and fitted values of the total dry weight for the species *Abies alba*.
Fig. 7 - Rappresentazione grafica dei valori osservati e stimati del peso secco totale del fusto e rami grossi per la specie Abies alba.

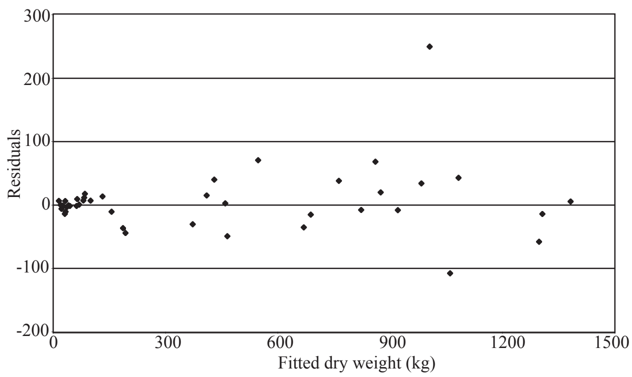

Fig. 8 - Residuals of the total dry weight regression for the species *Abies alba*.
Fig. 8 - Valori residui del peso secco totale del fusto e rami grossi per la specie Abies alba.

Tab. 25 - Frequencies of the selected trees for the species *Larix decidua* by dimensional classes.
Tab. 25 - Frequenze degli alberi campione della specie Larix decidua *per classi dimensionali*.

Diameter classes (cm)	Height classes (m)						
	h<10	10≤h<15	15≤h<20	20≤h<25	25≤h<30	h≥30	Total
d<12.5	2	2	-	-	-	-	4
12.5≤d<22.5	2	3	7	-	-	-	12
22.5≤d<32.5	-	2	3	1	-	-	6
32.5≤d<42.5	-	-	2	3	-	-	5
d≥42.5	-	-	1	5	-	-	6
Total	4	7	13	9	-	-	33

Tab. 26 - Coefficients and standard error estimates of the prediction equations for the species *Larix decidua*.
Tab. 26 - Stime dei coefficienti e dei relativi errori standard nelle equazioni di previsione relative alla specie Larix decidua.

Dependent variable	Model structure $b_1 + b_2 d^2 h + b_3 d$					
	$\hat{b}_1$	$se(\hat{b}_1)$	$\hat{b}_2$	$se(\hat{b}_2)$	$\hat{b}_3$	$se(\hat{b}_3)$
Stem + Branch V (V)	8.8267	6.3189	$0.3426 \cdot 10^{-1}$	$0.0156 \cdot 10^{-1}$	$2.7518 \cdot 10^{-1}$	$8.1487 \cdot 10^{-1}$
Stem + Branch DW(w1)	$1.7603 \cdot 10$	5.6206	$1.9161 \cdot 10^{-2}$	$1.3895 \cdot 10^{-3}$	-1.8211	$7.2482 \cdot 10^{-1}$
Slash DW (w2)	-6.1618	7.0365	$-9.4460 \cdot 10^{-4}$	$1.7395 \cdot 10^{-3}$	2.1432	$9.0740 \cdot 10^{-1}$
Dead DW (w3)	2.2430	1.2285	$4.5782 \cdot 10^{-4}$	$3.0368 \cdot 10^{-4}$	$-1.5684 \cdot 10^{-1}$	$1.5842 \cdot 10^{-1}$
Stump DW (w4)	$-4.3937 \cdot 10^{-1}$	$6.5199 \cdot 10^{-1}$	$1.1090 \cdot 10^{-4}$	$1.6118 \cdot 10^{-4}$	$1.5787 \cdot 10^{-1}$	$8.4078 \cdot 10^{-2}$
AG DW (wtot)	$1.3245 \cdot 10$	8.6570	$1.8785 \cdot 10^{-2}$	$2.1401 \cdot 10^{-3}$	$3.2315 \cdot 10^{-1}$	1.1164

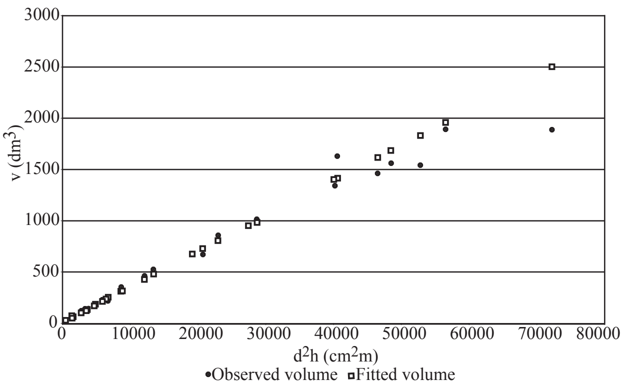

Fig. 9 - Observed and fitted values of the stem and branch volume for the species *Larix decidua*.
Fig. 9 - Rappresentazione grafica dei valori osservati e stimati del volume del fusto e rami grossi per la specie Larix decidua.

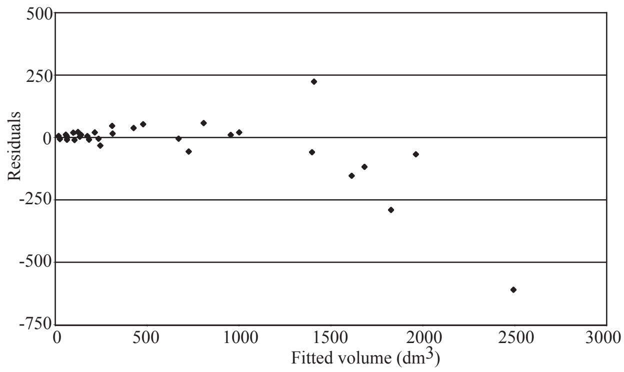

Fig. 10 - Residuals of the stem and branch volume regression for the species *Larix decidua*.
Fig. 10 - Valori residui del volume del fusto e rami grossi per la specie Larix decidua.

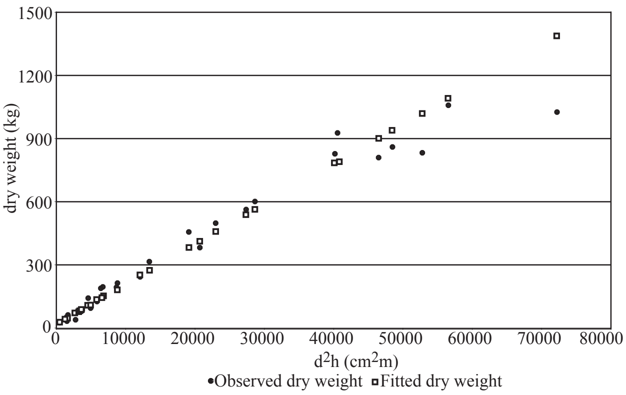

Fig. 11 - Observed and fitted values of the total dry weight for the species *Larix decidua*.
Fig. 11 - Rappresentazione grafica dei valori osservati e stimati del peso secco totale del fusto e rami grossi per la specie Larix decidua.

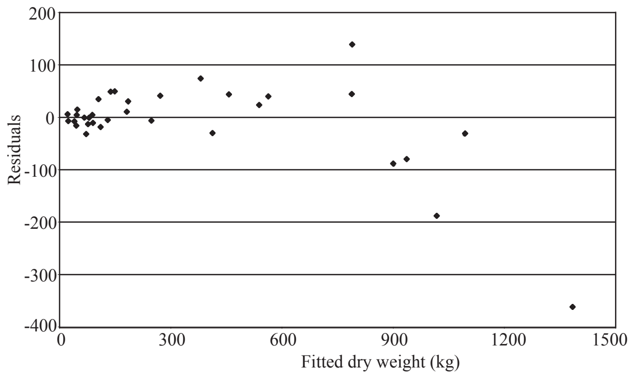

Fig. 12 - Residuals of the total dry weight regression for the species *Larix decidua*.
Fig. 12 - Valori residui del peso secco totale del fusto e rami grossi per la specie Larix decidua.

Tab. 27 - Frequencies of the selected trees for the species *Pinus sylvestris* by dimensional classes.
Tab. 27 - Frequenze degli alberi campione della specie Pinus sylvestris *per classi dimensionali.*

Diameter classes (cm)	Height classes (m)						
	h<10	10≤h<15	15≤h<20	20≤h<25	25≤h<30	h≥30	Total
d<12.5	3	3	-	-	-	-	6
12.5≤d<22.5	6	5	2	-	-	-	13
22.5≤d<32.5	-	2	3	-	-	-	5
32.5≤d<42.5	-	3	2	1	-	-	6
d≥42.5	-	-	-	-	-	-	-
Total	9	13	7	1	-	-	30

Tab. 28 - Coefficients and standard error estimates of the prediction equations for the species *Pinus sylvestris*.
Tab. 28 - Stime dei coefficienti e dei relativi errori standard nelle equazioni di previsione relative alla specie Pinus sylvestris.

Dependent variable	Model structure $b_1 + b_2 d^2 h$					
	$\hat{b}_1$	$se(\hat{b}_1)$	$\hat{b}_2$	$se(\hat{b}_2)$	$\hat{b}_3$	$se(\hat{b}_3)$
Stem + Branch V (V)	2.6374	3.1076	$0.4102 \cdot 10^{-1}$	$0.0180 \cdot 10^{-1}$	-	-
Stem + Branch DW (w1)	$-7.3626 \cdot 10^{-2}$	1.6390	$1.8465 \cdot 10^{-2}$	$9.4704 \cdot 10^{-4}$	-	-
Slash DW (w2)	2.5406	1.3526	$4.2895 \cdot 10^{-3}$	$7.8154 \cdot 10^{-4}$	-	-
Dead DW (w3)	$1.4696 \cdot 10^{-1}$	$2.2507 \cdot 10^{-1}$	$6.8895 \cdot 10^{-4}$	$1.3005 \cdot 10^{-4}$	-	-
Stump DW (w4)	$9.4123 \cdot 10^{-2}$	$6.6426 \cdot 10^{-2}$	$2.8144 \cdot 10^{-4}$	$3.8383 \cdot 10^{-5}$	-	-
AG DW (wtot)	2.7081	2.4017	$2.3724 \cdot 10^{-2}$	$1.3878 \cdot 10^{-3}$	-	-

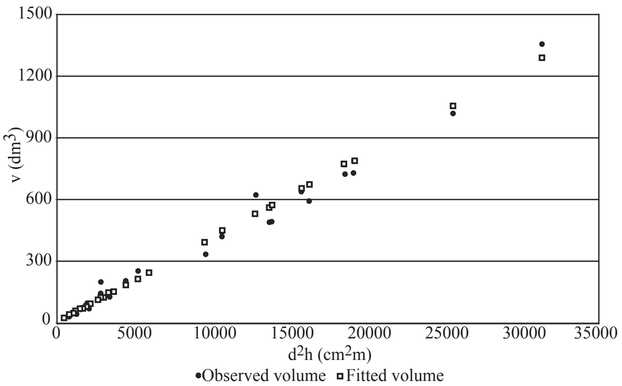

Fig. 13 - Observed and fitted values of the stem and branch volume for the species *Pinus sylvestris*.
Fig. 13 - Rappresentazione grafica dei valori osservati e stimati del volume del fusto e rami grossi per la specie Pinus sylvestris.

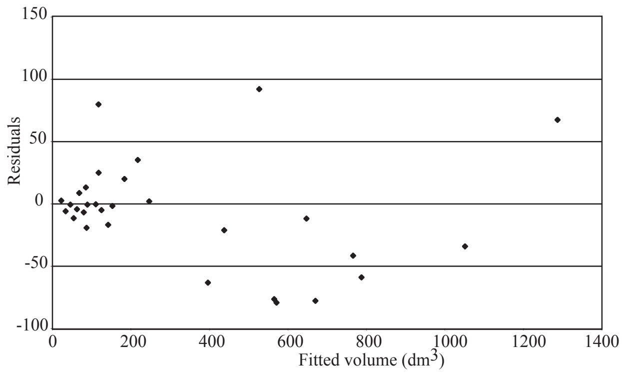

Fig. 14 - Residuals of the stem and branch volume regression for the species *Pinus sylvestris*.
Fig. 14 - Valori residui del volume del fusto e rami grossi per la specie Pinus sylvestris.

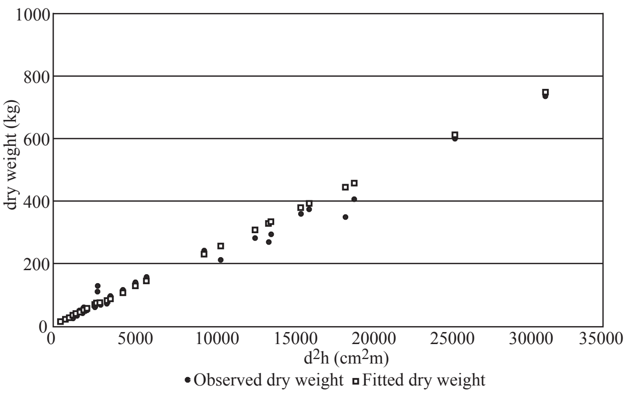

Fig. 15 - Observed and fitted values of the total dry weight for the species *Pinus sylvestris*.
Fig. 15 - Rappresentazione grafica dei valori osservati e stimati del peso secco totale del fusto e rami grossi per la specie Pinus sylvestris.

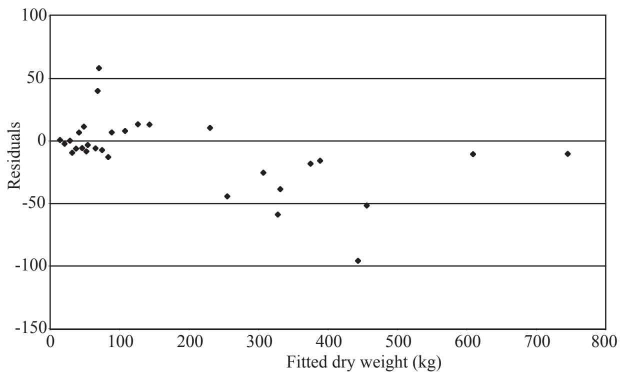

Fig. 16 - Residuals of the total dry weight regression for the species *Pinus sylvestris*.
Fig. 16 - Valori residui del peso secco totale del fusto e rami grossi per la specie Pinus sylvestris.

Tab. 29 - Frequencies of the selected trees for the species *Pinus nigra* by dimensional classes.
Tab. 29 - Frequenze degli alberi campione della specie Pinus nigra *per classi dimensionali.*

Diameter classes (cm)	Height classes (m)						
	h<10	10≤h<15	15≤h<20	20≤h<25	25≤h<30	h≥30	Total
d<12.5	3	2	-	-	-	-	5
12.5≤d<22.5	7	3	1	-	-	-	11
22.5≤d<32.5	1	5	4	1	-	-	11
32.5≤d<42.5	-	1	2	-	-	-	3
d≥42.5	-	-	-	-	-	-	-
Total	11	11	7	1	-	-	30

Tab. 30 - Coefficients and standard error estimates of the prediction equations for the species *Pinus nigra*.
Tab. 30 - Stime dei coefficienti e dei relativi errori standard nelle equazioni di previsione relative alla specie Pinus nigra.

Dependent variable	Model structure $b_1 + b_2d^2h + b_3d^2$					
	$\hat{b}_1$	$se(\hat{b}_1)$	$\hat{b}_2$	$se(\hat{b}_2)$	$\hat{b}_3$	$se(\hat{b}_3)$
Stem + Branch V (V)	-5.6704	2.1555	$3.1896\cdot10^{-2}$	$2.3130\cdot10^{-3}$	0.1271	$2.8494\cdot10^{-2}$
Stem + Branch DW (w1)	-3.5712	1.3682	$1.4429\cdot10^{-2}$	$1.4681\cdot10^{-3}$	$6.8047\cdot10^{-2}$	$1.8086\cdot10^{-2}$
Slash DW (w2)	-8.7135	1.8489	$-6.7203\cdot10^{-4}$	$1.9840\cdot10^{-3}$	$1.1893\cdot10^{-1}$	$2.4441\cdot10^{-2}$
Dead DW (w3)	$-6.7033\cdot10^{-1}$	$2.4300\cdot10^{-1}$	$4.0558\cdot10^{-5}$	$2.6076\cdot10^{-4}$	$1.0169\cdot10^{-2}$	$3.2123\cdot10^{-3}$
Stump DW (w4)	$-3.0325\cdot10^{-3}$	$9.4179\cdot10^{-2}$	$9.5000\cdot10^{-6}$	$1.0106\cdot10^{-4}$	$4.9117\cdot10^{-3}$	$1.2450\cdot10^{-3}$
AG DW (wtot)	$-1.2958\cdot10$	2.5941	$1.3807\cdot10^{-2}$	$2.7837\cdot10^{-3}$	$2.0206\cdot10^{-1}$	$3.4292\cdot10^{-2}$

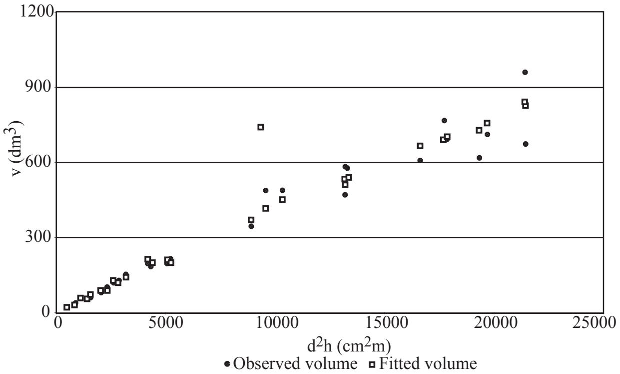

Fig. 17 - Observed and fitted values of the stem and branch volume for the species *Pinus nigra*.
Fig. 17 - Rappresentazione grafica dei valori osservati e stimati del volume del fusto e rami grossi per la specie Pinus nigra.

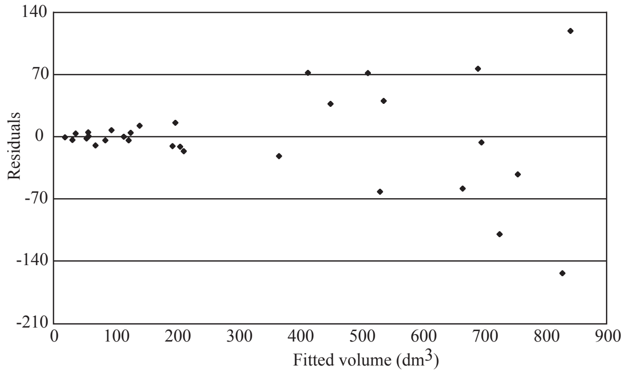

Fig. 18 - Residuals of the stem and branch volume regression for the species *Pinus nigra*.
Fig. 18 - Valori residui del volume del fusto e rami grossi per la specie Pinus nigra.

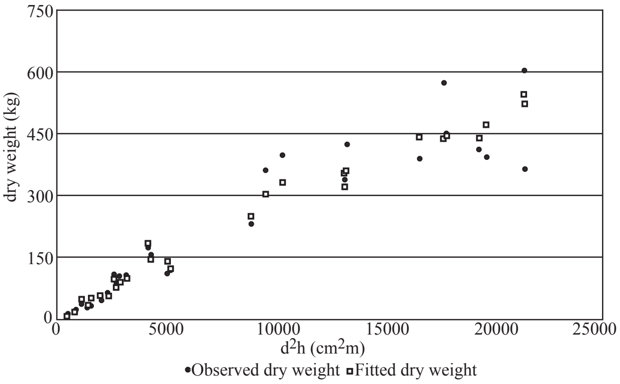

Fig. 19 - Observed and fitted values of the total dry weight for the species *Pinus nigra*.
Fig. 19 - Rappresentazione grafica dei valori osservati e stimati del peso secco totale del fusto e rami grossi per la specie Pinus nigra.

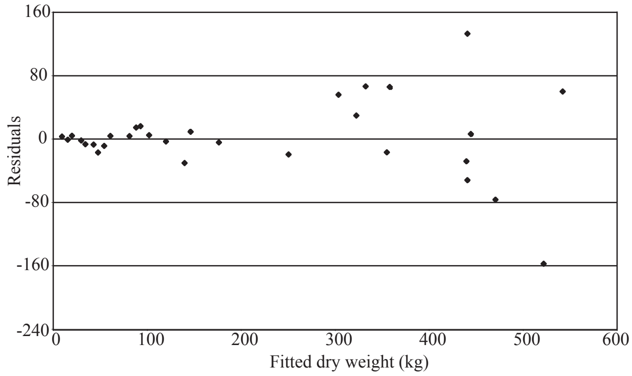

Fig. 20 - Residuals of the total dry weight regression for the species *Pinus nigra*.
Fig. 20 - Valori residui del peso secco totale del fusto e rami grossi per la species Pinus nigra.

Tab. 31 - Frequencies of the selected trees for the species *Pinus cembra* by dimensional classes.
Tab. 31 - Frequenze degli alberi campione della specie Pinus cembra *per classi dimensionali.*

Diameter classes (cm)	Height classes (m)						
	h<10	10≤h<15	15≤h<20	20≤h<25	25≤h<30	h≥30	Total
d<12.5	4	-	-	-	-	-	4
12.5≤d<22.5	2	5	2	-	-	-	9
22.5≤d<32.5	-	4	2	-	-	-	6
32.5≤d<42.5	-	-	3	-	-	-	3
d≥42.5	-	-	7	1	-	-	8
Total	6	9	14	1	-	-	30

Tab. 32 - Coefficients and standard error estimates of the prediction equations for the species *Pinus cembra*.
Tab. 32 - Stime dei coefficienti e dei relativi errori standard nelle equazioni di previsione relative alla specie Pinus cembra*.*

Dependent variable	Model structure $b_1 + b_2 d^2 h + b_3 d^2$					
	$\hat{b}_1$	$se(\hat{b}_1)$	$\hat{b}_2$	$se(\hat{b}_2)$	$\hat{b}_3$	$se(\hat{b}_3)$
Stem + Branch V (V)	-5.5632	2.5613	$3.0080 \cdot 10^{-2}$	$0.0330 \cdot 10^{-1}$	0.1546	$0.5218 \cdot 10^{-1}$
Stem + Branch DW (w1)	-2.9695	1.0113	$1.0066 \cdot 10^{-2}$	$1.3026 \cdot 10^{-3}$	$8.4233 \cdot 10^{-2}$	$2.0604 \cdot 10^{-2}$
Slash DW (w2)	$6.4194 \cdot 10^{-1}$	$9.0970 \cdot 10^{-1}$	$-1.5615 \cdot 10^{-4}$	$1.1717 \cdot 10^{-3}$	$3.9256 \cdot 10^{-2}$	$1.8534 \cdot 10^{-2}$
Dead DW (w3)	-1.0563	$3.2674 \cdot 10^{-1}$	$9.7619 \cdot 10^{-6}$	$4.2085 \cdot 10^{-4}$	$1.6480 \cdot 10^{-2}$	$6.6567 \cdot 10^{-3}$
Stump DW (w4)	$-4.2908 \cdot 10^{-2}$	$1.9635 \cdot 10^{-1}$	$3.3702 \cdot 10^{-4}$	$2.5290 \cdot 10^{-4}$	$1.4672 \cdot 10^{-3}$	$4.0003 \cdot 10^{-3}$
AG DW (wtot)	-3.4268	1.3511	$1.0256 \cdot 10^{-2}$	$1.7403 \cdot 10^{-3}$	$1.4144 \cdot 10^{-1}$	$2.7527 \cdot 10^{-2}$

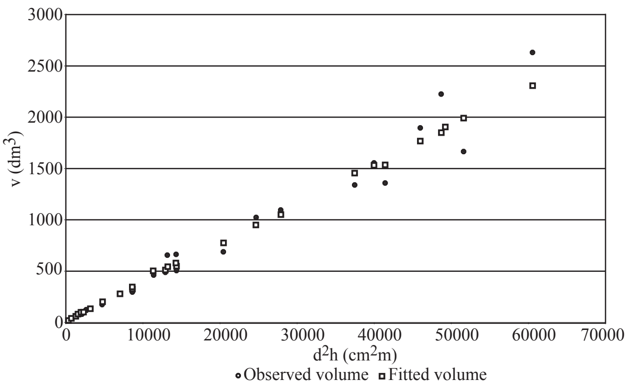

Fig. 21 - Observed and fitted values of the stem and branch volume for the species *Pinus cembra*.
Fig. 21 - Rappresentazione grafica dei valori osservati e stimati del volume del fusto e rami grossi per la specie Pinus cembra.

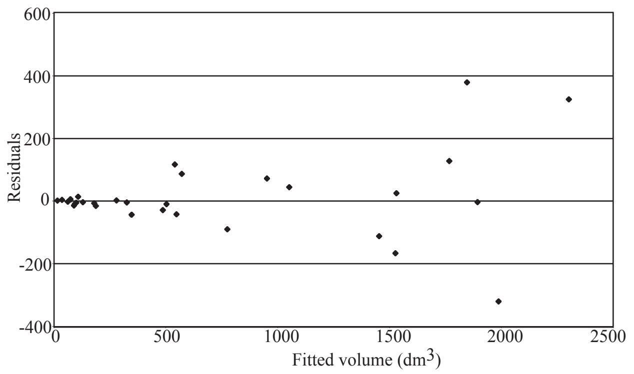

Fig. 22 - Residuals of the stem and branch volume regression for the species *Pinus cembra.*
Fig. 22 - Valori residui del volume del fusto e rami grossi per la specie Pinus cembra.

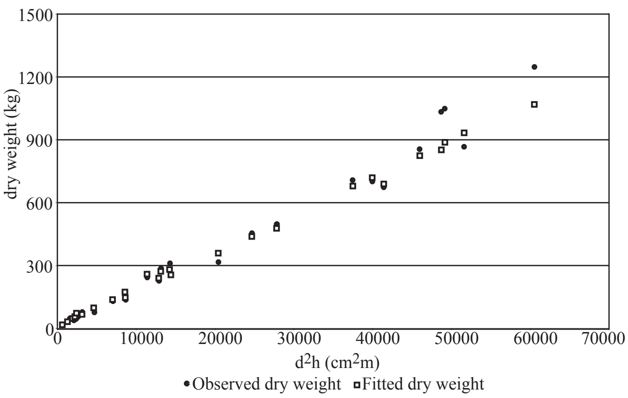

Fig. 23 - Observed and fitted values of the total dry weight for the species *Pinus cembra.*
Fig. 23 - Rappresentazione grafica dei valori osservati e stimati del peso secco totale del fusto e rami grossi per la specie Pinus cembra.

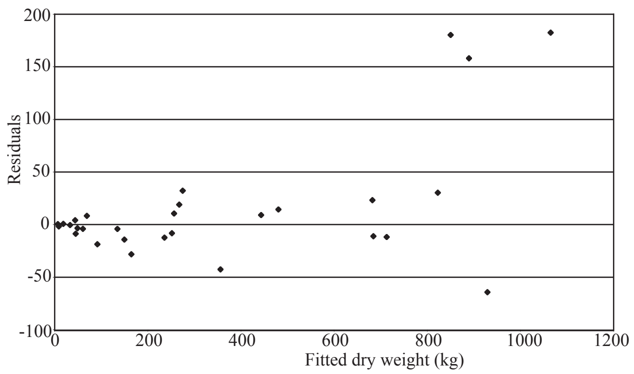

Fig. 24 - Residuals of the total dry weight regression for the species *Pinus cembra*.
Fig. 24 - Valori residui del peso secco totale del fusto e rami grossi per la specie Pinus cembra.

Tab. 33 - Frequencies of the selected trees for the species *Fagus sylvatica* by dimensional classes.
Tab. 33 - Frequenze degli alberi campione della specie Fagus sylvatica *per classi dimensionali.*

Diameter classes (cm)	Height classes (m)						
	h<10	10≤h<15	15≤h<20	20≤h<25	25≤h<30	h≥30	Total
d<12.5	-	3	1	-	-	-	4
12.5≤d<22.5	1	3	6	-	-	-	10
22.5≤d<32.5	-	4	3	1	-	-	8
32.5≤d<42.5	-	-	4	-	-	-	4
d≥42.5	-	-	2	2	-	-	4
Total	1	10	16	3	-	-	30

Tab. 34 - Coefficients and standard error estimates of the prediction equations for the species *Fagus sylvatica*.
Tab. 34 - Stime dei coefficienti e dei relativi errori standard nelle equazioni di previsione relative alla specie Fagus sylvatica.

Dependent variable	Model structure $b_1 + b_2d^2h + b_3d^2$					
	$\hat{b}_1$	$se(\hat{b}_1)$	$\hat{b}_2$	$se(\hat{b}_2)$	$\hat{b}_3$	$se(\hat{b}_3)$
Stem + Branch V (V)	-8.0150	9.5312	$0.3108 \cdot 10^{-1}$	$0.0936 \cdot 10^{-1}$	$1.8083 \cdot 10^{-1}$	$1.6588 \cdot 10^{-1}$
Stem + Branch DW (w1)	-3.7197	6.0288	$1.9559 \cdot 10^{-2}$	$5.9197 \cdot 10^{-3}$	$8.8089 \cdot 10^{-2}$	$1.0492 \cdot 10^{-1}$
Slash DW (w2)	-5.5870	2.9109	$-1.9468 \cdot 10^{-3}$	$2.8583 \cdot 10^{-3}$	$1.5641 \cdot 10^{-1}$	$5.0660 \cdot 10^{-2}$
Dead DW (w3)	$-3.2310 \cdot 10^{-1}$	$4.6338 \cdot 10^{-1}$	$5.0689 \cdot 10^{-4}$	$4.5499 \cdot 10^{-4}$	$-3.5765 \cdot 10^{-3}$	$8.0643 \cdot 10^{-3}$
Stump DW (w4)	-1.1678	$4.8980 \cdot 10^{-1}$	$-1.0182 \cdot 10^{-4}$	$4.8093 \cdot 10^{-4}$	$1.7957 \cdot 10^{-2}$	$8.5241 \cdot 10^{-3}$
AG DW (wtot)	$-1.0798 \cdot 10$	7.8180	$1.8017 \cdot 10^{-2}$	$7.6765 \cdot 10^{-3}$	$2.5888 \cdot 10^{-1}$	$1.3606 \cdot 10^{-1}$

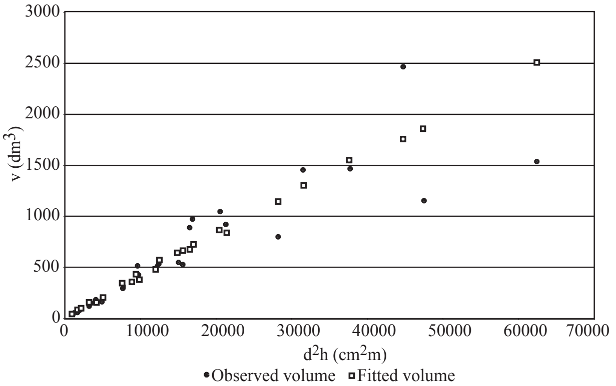

Fig. 25 - Observed and fitted values of the stem and branch volume for the species *Fagus sylvatica*.
Fig. 25 - Rappresentazione grafica dei valori osservati e stimati del volume del fusto e rami grossi per la specie Fagus sylvatica.

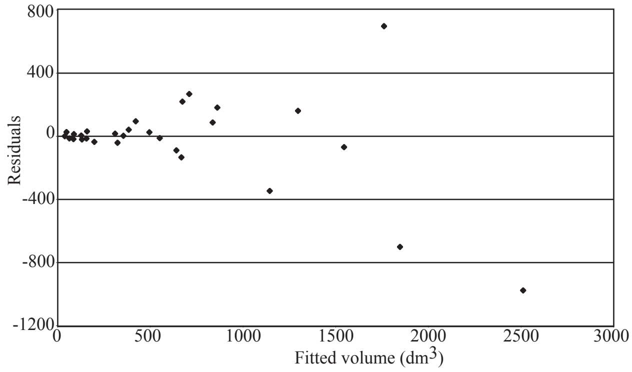

Fig. 26 - Residuals of the stem and branch volume regression for the species *Fagus sylvatica*.
Fig. 26 - Valori residui del volume del fusto e rami grossi per la specie Fagus sylvatica.

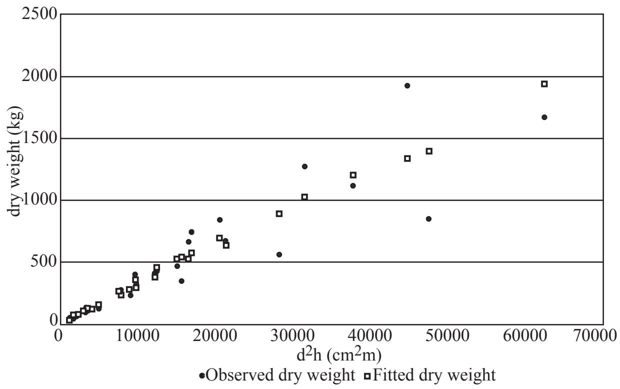

Fig. 27 - Observed and fitted values of the total dry weight for the species *Fagus sylvatica*.
Fig. 27 - Rappresentazione grafica dei valori osservati e stimati del peso secco totale del fusto e rami grossi per la specie Fagus sylvatica.

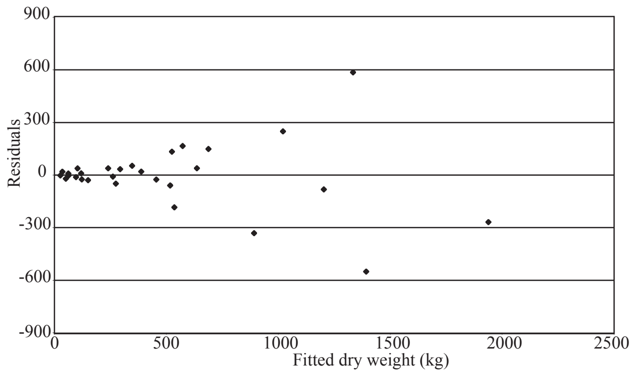

Fig. 28 - Residuals of the total dry weight regression for the species *Fagus sylvatica*.
Fig. 28 - Valori residui del peso secco totale del fusto e rami grossi per la specie Fagus sylvatica.

Tab. 35 - Frequencies of the selected trees for the group *Ostrya carpinifolia* and other similar tree species by dimensional classes.
Tab. 35 - Frequenze degli alberi campione del gruppo Ostrya carpinifolia *ed altre specie simili per classi dimensionali.*

Diameter classes (cm)	Height classes (m)						
	h<10	10≤h<15	15≤h<20	20≤h<25	25≤h<30	h≥30	Total
d<12.5	18	4	-	-	-	-	22
12.5≤d<22.5	4	8	3	-	-	-	15
22.5≤d<32.5	-	-	3	-	-	-	3
32.5≤d<42.5	-	-	-	-	-	-	-
d≥42.5	-	-	-	-	-	-	-
Total	22	12	6	-	-	-	40

Tab. 36 - Coefficients and standard error estimates of the prediction equations for the group *Ostrya carpinifolia* and other similar tree species.
Tab. 36 - Stime dei coefficienti e dei relativi errori standard nelle equazioni di previsione relative al gruppo Ostrya carpinifolia *e altre specie simili.*

Dependent variable	Model structure $b_1 + b_2d^2h + b_3d^2$					
	$\hat{b}_1$	$se(\hat{b}_1)$	$\hat{b}_2$	$se(\hat{b}_2)$	$\hat{b}_3$	$se(\hat{b}_3)$
Stem + Branch V (V)	-5.4732	1.0436	$0.2448 \cdot 10^{-1}$	$0.0457 \cdot 10^{-1}$	$2.3231 \cdot 10^{-1}$	$0.5218 \cdot 10^{-1}$
Stem + Branch DW (w1)	-4.6965	$8.7107 \cdot 10^{-1}$	$1.2034 \cdot 10^{-2}$	$3.8122 \cdot 10^{-3}$	$2.1771 \cdot 10^{-1}$	$4.3559 \cdot 10^{-2}$
Slash DW (w2)	$2.7434 \cdot 10^{-1}$	1.1566	$-6.8965 \cdot 10^{-3}$	$5.0620 \cdot 10^{-3}$	$1.8006 \cdot 10^{-1}$	$5.7839 \cdot 10^{-2}$
Dead DW (w3)	$-9.2522 \cdot 10^{-2}$	$6.4291 \cdot 10^{-2}$	$-3.4284 \cdot 10^{-4}$	$2.8137 \cdot 10^{-4}$	$7.2860 \cdot 10^{-3}$	$3.2150 \cdot 10^{-3}$
Stump DW (w4)	$-7.3006 \cdot 10^{-2}$	$8.6474 \cdot 10^{-2}$	$4.6921 \cdot 10^{-4}$	$3.7845 \cdot 10^{-4}$	$3.9370 \cdot 10^{-3}$	$4.3242 \cdot 10^{-3}$
AG DW (wtot)	-4.5877	1.6025	$5.2638 \cdot 10^{-3}$	$7.0132 \cdot 10^{-3}$	$4.0900 \cdot 10^{-1}$	$8.0134 \cdot 10^{-2}$

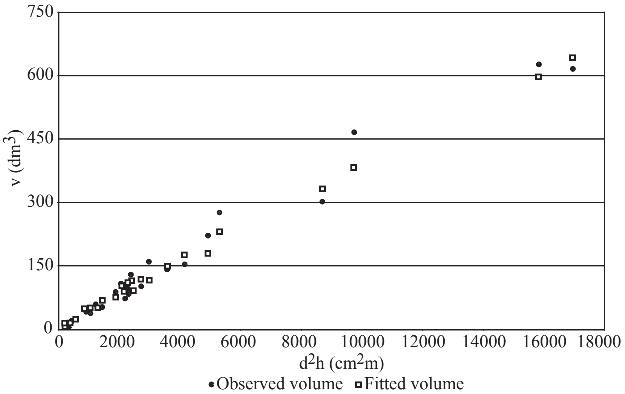

Fig. 29 - Observed and fitted values of the stem and branch volume for the group *Ostrya carpinifolia* and other similar tree species.
Fig. 29 - Rappresentazione grafica dei valori osservati e stimati del volume del fusto e rami grossi per il gruppo Ostrya carpinifolia *e altre specie simili.*

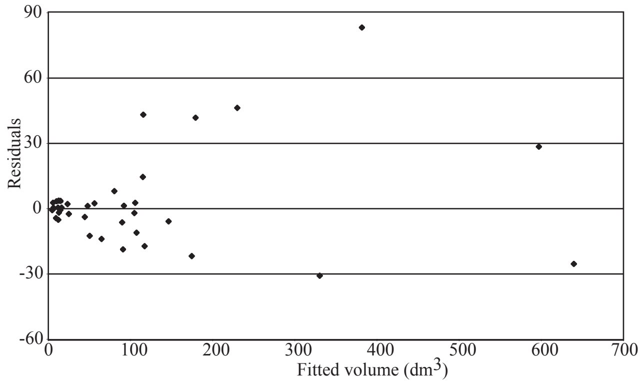

Fig. 30 - Residuals of the stem and branch volume regression for the group *Ostrya carpinifolia* and other similar tree species.
Fig. 30 - Valori residui del volume del fusto e rami grossi per il gruppo Ostrya carpinifolia *e altre specie simili.*

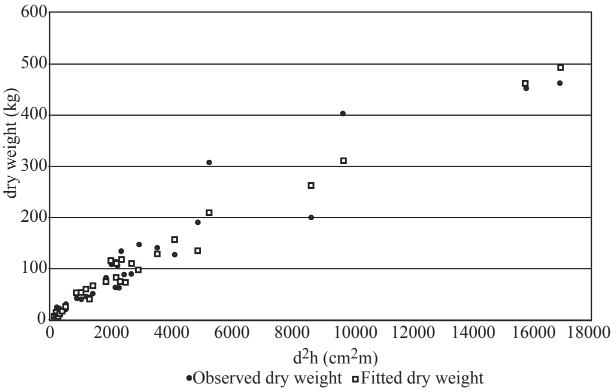

Fig. 31 - Observed and fitted values of the total dry weight for the group *Ostrya carpinifolia* and other similar tree species.
Fig. 31 - Rappresentazione grafica dei valori osservati e stimati del peso secco totale del fusto e rami grossi per il gruppo Ostrya carpinifolia *ed altre specie simili.*

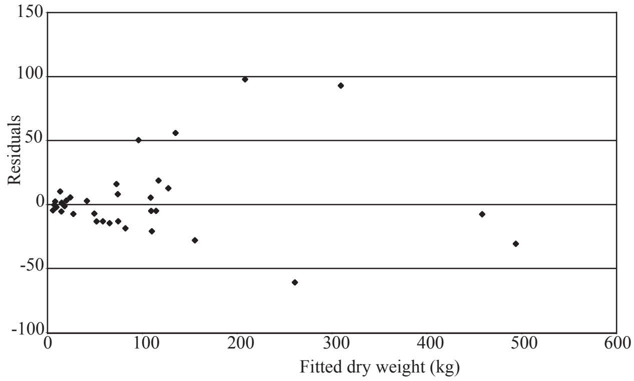

Fig. 32 - Residuals of the total dry weight regression for the group *Ostrya carpinifolia* and other similar species.
Fig. 32 - Valori residui del peso secco totale del fusto e rami grossi per il gruppo Ostrya carpinifolia *e altre specie simili.*

Tab. 37 - Frequencies of the selected trees for the group *Castanea sativa* and other similar tree species by dimensional classes.
Tab. 37 - Frequenze degli alberi campione del gruppo Castanea sativa *ed altre specie simili per classi dimensionali.*

Diameter classes (cm)	Height classes (m)						
	h<10	10≤h<15	15≤h<20	20≤h<25	25≤h<30	h≥30	Total
d<12.5	7	6	-	-	-	-	13
12.5≤d<22.5	2	6	3	-	-	-	11
22.5≤d<32.5	1	-	-	1	-	-	2
32.5≤d<42.5	-	-	1	1	-	-	2
d≥42.5	-	-	-	-	-	-	-
Total	10	12	4	2	-	-	28

Tab. 38 - Coefficients and standard error estimates of the prediction equations for the group *Castanea sativa* and other similar tree species.
Tab. 38 - Stime dei coefficienti e dei relativi errori standard nelle equazioni di previsione relative al gruppo Castanea sativa *e altre specie simili.*

Dependent variable	Model structure $b_1 + b_2d^2h + b_3d^2$					
	$\hat{b}_1$	$se(\hat{b}_1)$	$\hat{b}_2$	$se(\hat{b}_2)$	$\hat{b}_3$	$se(\hat{b}_3)$
Stem + Branch V (V)	-2.4818	2.2475	$0.2788 \cdot 10^{-1}$	$0.0472 \cdot 10^{-1}$	$1.1537 \cdot 10^{-1}$	$0.5851 \cdot 10^{-1}$
Stem + Branch DW (w1)	$2.1616 \cdot 10^{-1}$	1.4839	$1.4282 \cdot 10^{-2}$	$3.1171 \cdot 10^{-3}$	$4.4323 \cdot 10^{-2}$	$3.8631 \cdot 10^{-2}$
Slash DW (w2)	$7.3436 \cdot 10^{-2}$	$8.6864 \cdot 10^{-1}$	$-5.0700 \cdot 10^{-3}$	$1.8247 \cdot 10^{-3}$	$1.5037 \cdot 10^{-1}$	$2.2614 \cdot 10^{-2}$
Dead DW (w3)	$-8.7737 \cdot 10^{-3}$	$1.9444 \cdot 10^{-1}$	$7.8059 \cdot 10^{-4}$	$4.0844 \cdot 10^{-4}$	$-3.0046 \cdot 10^{-3}$	$5.0619 \cdot 10^{-3}$
Stump DW (w4)	$-9.9791 \cdot 10^{-2}$	$4.3695 \cdot 10^{-1}$	$7.4754 \cdot 10^{-4}$	$9.1785 \cdot 10^{-4}$	$1.0198 \cdot 10^{-2}$	$1.1375 \cdot 10^{-2}$
AG DW (wtot)	$1.8104 \cdot 10^{-1}$	1.6333	$1.0740 \cdot 10^{-2}$	$3.4309 \cdot 10^{-3}$	$2.0189 \cdot 10^{-1}$	$4.2520 \cdot 10^{-2}$

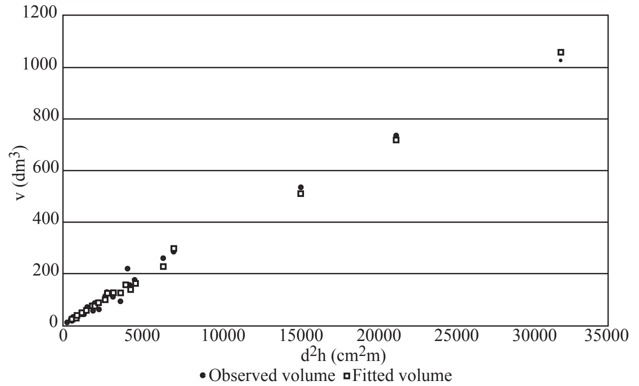

Fig. 33 - Observed and fitted values of the stem and branch volume for the group *Castanea sativa* and other similar tree species.
Fig. 33 - Rappresentazione grafica dei valori osservati e stimati del volume del fusto e rami grossi per il gruppo Castanea sativa *e altre specie simili.*

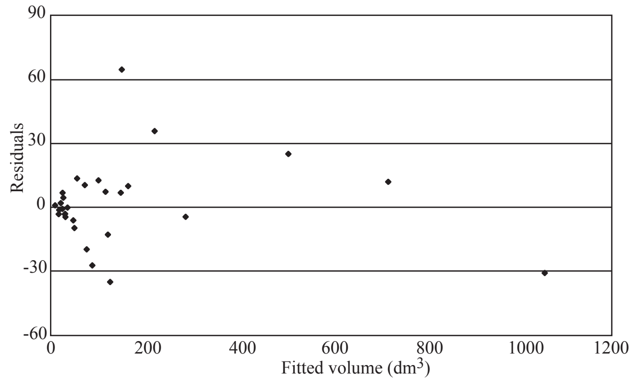

Fig. 34 - Residuals of the stem and branch volume regression for the group *Castanea sativa* and other similar tree species.
Fig. 34 - Valori residui del volume del fusto e rami grossi per il gruppo Castanea sativa *e altre specie simili.*

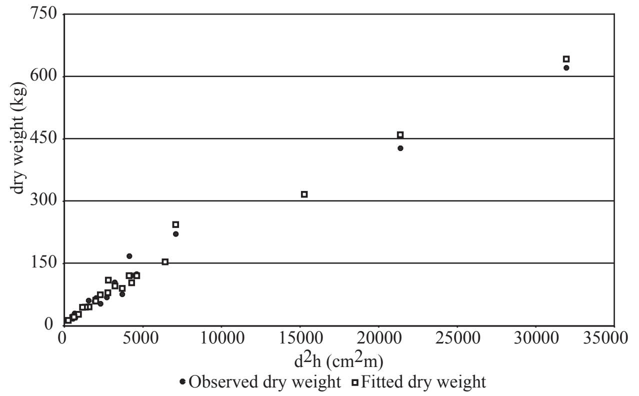

Fig. 35 - Observed and fitted values of the total dry weight for the group *Castanea sativa* and other similar tree species.
Fig. 35 - Rappresentazione grafica dei valori osservati e stimati del peso secco totale del fusto e rami grossi per il gruppo Castanea sativa *e altre specie simili.*

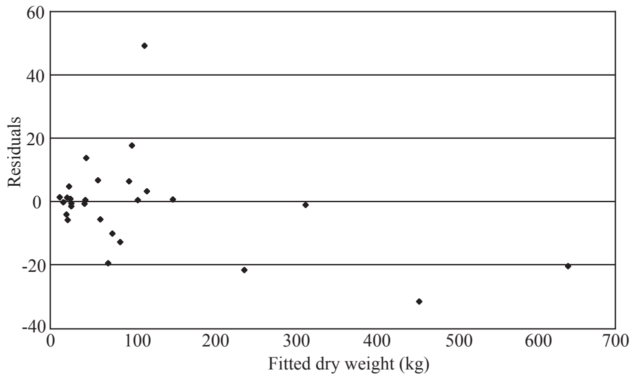

Fig. 36 - Residuals of the total dry weight regression for the group *Castanea sativa* and other similar tree species.
Fig. 36 - Valori residui del peso secco totale del fusto e rami grossi per il gruppo Castanea sativa *e altre specie simili.*

obtained from separate surveys, the variance estimates for the total phytomass is once again obtained as the sum of the variance estimates for each species.

At Lavazè Pass, for each winter, the volume and phytomass of any single tree were predicted by using the prediction equations of *Picea abies* (L.) Karsten (Tab. 22) and *Pinus cembra* L. (Tab. 32), which are the only softwoods present in the area, while for Pomarolo, the prediction equations of the softwoods *Larix decidua* Miller (Tab. 26), *Pinus sylvestris* L. (Table 28) and *Picea abies* (Tab. 22) were adopted together with the equations in table 36 for predicting the volume and phytomass of *Quercus pubescens* Willd., *Fraxinus ornus* L. and *Ostrya carpinifolia* Scop. and the equations in table 38 for predicting other hardwoods.

For each species or species group, tables 39 and 40 report the predictions of volume and above-ground phytomass components per unit area together with the estimates of the corresponding standard errors. As suggested by Matthews (1993), the phytomass predictions multiplied by 0.5 provide quite accurate predictions of the carbon stocked in the stands. Accordingly, 73.3 Mg ha^{-1} of carbon was estimated in the above-ground forest components of Pomarolo stand during the winter 2004-2005, with an estimated standard error of 2.8 %, while a much higher carbon stock of 217.4 Mg ha^{-1} was estimated during the same winter for the above-ground forest components of Lavazè Pass, with an estimated standard error of 3.4 %. However, it is worth noting that the calculations for the Pomarolo area neglected the massive presence of dead or prostrate trees and snags, with a density of 212 plants (of several species) per hectare and a basal area of 1.02 m^2 ha^{-1}. However, no model-based prediction of their volume and phytomass was attemped, since peculiar dead-wood estimation procedures were more suitable in these cases.

4. A PRELIMINARY ASSESSMENT OF ABOVE-GROUND SHRUB PHYTOMASS

On the basis of the results of the first National Forest Inventory (NFI) performed in 1985, the extent of shrub stands in Italy was estimated to be about 1.5 million hectares, corresponding to 17% of the total forest area. Unfortunately, other inventory information about this relevant component of Italian vegetation was almost lacking. Indeed, the 1988 NFI results contained only details on the potential evolution of shrub stands (according to which about 40% of Italian shrub stands were stable at that time) and details on the relative frequency of the main species (according to which *Cistus* L. stands represented the 14.6% of the total shrub area, *Pistacia lentiscus* L. represented 9.5% and *Juniperus communis* L. only 2.4%). However, no division into the different types of shrub stands and no quantitative information on density and phytomass were available. For these reasons, intensive monitoring and a classification study of shrub stands were planned as part of the second National Forest Inventory (INFC 2003) while a preliminary investigation into the extent of the above-ground phytomass of shrub stands was also planned in the Province of Trento as part of the EFOMI project. Moreover, this study was also aimed at assessing the correlation between above-ground shrub phytomass and the height and density of stands in order to give some insight into the feasibility of models predicting shrub phytomass by means of height and density.

To this purpose, surveys were performed in some selected areas of Trentino. The above-ground shrub stand in a quadrat of size 3 m was collected and the fresh weight was subsequently measured. Then, small samples measuring a few kilos were collected from the shrub stand in each plot, the samples were subsequently stove-dried and the ratio of dry weight to fresh weight was determined. As is well known, by means of this ratio the evaluation of the total dry weight in a plot (and hence the phytomass per unit area) is possible whenever the total fresh weight of the plot is available. Moreover, for each sample plot, the mean height of the shrubs was quantified together with their crown cover, which was determined by means of a regular grid of points.

It is worth noting that the information collected in this study must be viewed only as a preliminary assessment of shrub stands in Trentino and cannot be used to make any statistical design-based inference because the data were subjectively collected without any probabilistic sampling scheme. Table 41 reports the frequencies of the sample plots by forest district and type of shrub stand, which, in turn, are classified in accordance with the scheme adopted in the second National Forest Inventory. Moreover, table 42 contains some descriptive statistics regarding the mean height, crown cover, dry weight and its ratio to fresh weight. Table 43 reports the values of the correlation coefficient between height and crown cover to dry weight for those stands in which an adequate number of sample plots was surveyed.

5. CONCLUSIONS

As a main result of this study, the Province of Trento is now the first Italian locality to possess a collection of prediction models to evaluate the above-ground tree phytomass for a considerably comprehensive list of forest species. Seven prediction equations were constructed for spruce, fir, larch, Scots pine, black pine, Swiss stone-pine and beech, while two prediction equations were prepared for the group referred to as *Ostrya carpinifolia* and other similar tree species, including hornbeam, holm-oak, downy-oak, ash, and false acacia, as well as for the group referred to as *Castanea sativa* and other similar tree species, including chestnut,

Tab. 39 - Volume and phytomass predictions with relative standard error estimates for the intensive monitoring area of Lavazè Pass.
Tab. 39 - Previsione dei principali attributi del soprassuolo con relativi errori standard per l'area di monitoraggio intensivo del Passo di Lavazè.

	Lavazè 1996-1997			Lavazè 1999-2000			Lavazè 2004-2005		
	Picea abies	*Pinus cembra*	Total	*Picea abies*	*Pinus cembra*	Total	*Picea abies*	*Pinus cembra*	Total
Number of trees per ha	388	4	392	388	4	392	388	4	392
Basal area (m^2 ha^{-1})	53.89	0.44	54.34	55.45	0.47	55.92	58.78	0.47	59.25
Stem and branch V (m^3 ha^{-1})	708.40	4.42	712.82	768.25	4.69	772.94	824.27	4.94	829.21
standard error	9.81	0.134	9.82	10.08	0.144	10.08	11.12	0.163	11.12
Stem and branch DW (Mg ha^{-1})	266.47	1.66	268.13	289.74	1.76	291.50	310.42	1.84	312.27
standard error	8.07	0.053	8.07	8.29	0.057	8.29	9.14	0.065	9.14
Slash DW (Mg ha^{-1})	91.80	0.21	92.01	96.34	0.22	96.55	104.85	0.22	105.07
standard error	11.84	0.047	11.84	12.16	0.051	12.16	13.41	0.058	13.41
Dead DW (Mg ha^{-1})	7.45	0.09	7.54	7.97	0.10	8.07	8.58	0.10	8.68
standard error	1.31	0.017	1.31	1.34	0.018	1.34	1.48	0.021	1.48
Stump DW (Mg ha^{-1})	7.65	0.05	7.70	8.08	0.05	8.13	8.78	0.05	8.83
standard error	0.61	0.010	0.61	0.63	0.011	0.63	0.69	0.013	0.69
AG DW (Mg ha^{-1})	373.37	2.00	375.38	402.12	2.12	404.25	432.63	2.21	434.85
standard error	12.87	0.070	12.90	13.22	0.076	13.22	14.58	0.086	14.58

Tab. 40 - Volume and phytomass predictions with relative standard error estimates for the intensive monitoring area of Pomarolo.
Tab. 40 - Previsione dei principali attributi del soprassuolo con relativi errori standard per l'area di monitoraggio intensivo di Pomarolo.

	Quercus pubescens	*Fraxinus ornus*	*Ostrya carpinifolia*	Other hard-woods	*Larix decidua*	*Pinus sylvestris*	*Picea abies*	Total
Number of trees per ha	744	436	272	60	40	28	4	1 584
Basal area (m^2 ha^{-1})	10.03	2.34	2.95	1.43	6.03	4.40	0.44	27.62
Stem and branch V (m^3 ha^{-1})	61.28	12.04	18.04	10.07	50.99	41.75	4.22	198.39
standard error	2.06	0.37	0.62	0.55	1.57	1.76	0.07	3.26
Stem and branch DW (Mg ha^{-1})	41.86	8.12	12.21	4.98	25.71	18.76	1.58	113.22
standard error	1.68	0.30	0.51	0.36	1.25	0.93	0.06	2.40
Slash DW (Mg ha^{-1})	13.16	3.37	3.79	1.26	1.96	4.43	0.60	28.57
standard error	2.24	0.40	0.68	0.21	1.56	0.77	0.08	2.95
Dead DW (Mg ha^{-1})	0.36	0.07	0.10	0.18	0.50	0.70	0.05	1.96
standard error	0.124	0.022	0.038	0.048	0.273	0.128	0.009	0.332
Stump DW (Mg ha^{-1})	1.13	0.23	0.34	0.40	0.41	0.29	0.05	2.85
standard error	0.167	0.030	0.050	0.107	0.145	0.038	0.004	0.256
AG DW (Mg ha^{-1})	56.51	11.79	16.43	6.82	28.58	24.18	2.27	146.58
standard error	3.10	0.56	0.94	0.40	1.92	1.37	0.09	4.06

Tab. 41 - Frequency of sample plots by forest district and shrub type.
Tab. 41 - Frequenza delle aree di saggio della fitomassa per distretto forestale e per tipo di formazione arbustiva.

Shrub type	Forest district				
(INFC)	Borgo Valsugana	Pergine	Primiero	Tione	Total
Subalpine shrubs					
- needle-leaved					
Pinus mugo stands			5	5	10
other needle-leaved shrub		3	2	5	10
- broadleaved					
subalpine moor		4	1	4	9
Alnus viridis stands		3	2	7	12
Salix stands	5				5
Temperate climate shrubs					
- needle-leaved					
Juniperus stands				2	2
- broadleaved					
Prunus and *Corilus* stands				5	5
other				4	4

Tab. 42 - Descriptive statistics for mean height, crown cover, fresh weight and dry weight in some shrub stands in Trentino.
Tab. 42 - Statistiche relative all'altezza media, alla copertura e al peso fresco e secco relative ad alcune formazioni arbustive del Trentino.

Shrub type		Mean height (m)	Crown cover (%)	Dry weight / fresh weight	Dry weight (Mg ha^{-1})
Subalpine shrubs					
- *Pinus mugo* stands	min	1.5	68.8	0.50	29.1
(n = 10)	mean	2.1	87.5	0.52	57.3
	max	3.5	100.0	0.56	92.8
	CV	(0.29)	(0.12)	(0.04)	(0.30)
- other needle-leaved shrubs	min	0.3	75.0	0.46	15.0
(n = 10)	mean	0.5	88.8	0.50	25.1
	max	0.7	100.0	0.56	46.1
	CV	(0.23)	(0.12)	(0.06)	(0.42)
- subalpine moor	min	0.5	50.0	0.46	9.3
(n = 9)	mean	0.6	84.7	0.50	25.0
	max	0.9	100.0	0.56	48.8
	CV	(0.23)	(0.20)	(0.08)	(0.44)
- *Alnus viridis* stands	min	1.6	62.5	0.49	20.4
(n = 12)	mean	3.4	94.3	0.53	68.1
	max	5.0	100.0	0.61	119.8
	CV	(0.33)	(0.11)	(0.06)	(0.42)
- *Salix* stands	min	3.2	81.3	0.34	37.6
(n = 5)	mean	4.0	91.3	0.47	69.2
	max	4.6	100.0	0.53	104.5
	CV	(0.16)	(0.09)	(0.16)	(0.41)
Temperate climate shrubs					
- Juniperus stands	min	1.0	50.0	0.50	8.2
(n = 2)	mean	1.0	53.1	0.52	8.7
	max	1.0	56.3	0.54	9.1
	CV	(0.00)	(0.08)	(0.05)	(0.08)
- *Prunus* and *Corilus* stands	min	4.8	87.5	0.51	62.3
(n = 5)	mean	5.2	96.3	0.54	85.1
	max	5.8	100.0	0.60	111.2
	CV	(0.07)	(0.06)	(0.07)	(0.26)
- other	min	3.0	62.5	0.48	8.2
(n = 4)	mean	3.2	75.0	0.51	24.8
	max	3.5	87.5	0.53	60.6
	CV	(0.07)	(0.14)	(0.05)	(0.97)

() pure number

Tab. 43 - Correlation coefficient between above-ground shrub phytomass (per unit area), mean height and crown cover observed in some shrub stands in Trentino.
Tab. 43 - Coefficienti di correlazione tra fitomassa arbustiva epigea (per unità di superficie), altezza media e copertura osservati in alcune formazioni arbustive del Trentino.

Shrub type	Number of item	Pearson correlation coefficient	
		Dry weight – mean height	Dry weight – crown cover
Subalpine shrubs	46	0.800	0.326
Pinus mugo stands	10	-0.028	-0.225
Other needle-leaved shrubs	10	0.367	0.886
Subalpine moors	9	0.585	0.775
Alnus viridis stands	12	0.707	0.021
Salix stands	5	0.865	0.885
Temperate climate shrubs	11	0.852	0.900
Juniperus stands	2	-	-
Prunus and *Corilus* stands	5	0.643	0.565
other	4	0.178	0.887
Total	57	0.746	0.492

maples, willows, and other broadleaves. As to the practical application of these equations, it must be noted that negative predictions of the volume and phytomass of trees in the small diameter and height classes may take place, as for black pines, Swiss stone-pines and beeches. In a few cases, negative prediction may also take place for firs, the chestnut group and other related minor species. However, these problems seem to be mainly due to the small number of observations made to fit some species models rather than to the validity of the model structure adopted in the work.

Finally, the study also provides some preliminary information on the above-ground phytomass of certain shrub stands in Trentino, such as mountain pine stands, subalpine moorlands, *Alnus viridis* stands and others stands contained in the classification adopted in the second National Forest Inventory. Even if the investigation may be viewed only as a preliminary assessment of the shrub stand characteristics, the results highlight a relevant correlation between phytomass and mean height and crown cover which may be useful for a future construction of suitable prediction models.

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Appendix 1 - Predicted values of volume and phytomass for the species *Picea abies* for several combinations of diameter and height.

Appendice 1 - Valori previsti del volume e della fitomassa relativi alla specie Picea abies *calcolati per diversi valori del diametro e dell'altezza.*

d (cm)	h (m)	6	10	14	18	22	26	30	34	38
10	V	25.7	44.5	67.1						
	w1	10.5	18.4	28.2						
	w2	8.3	7.8	5.4						
	w3	0.9	1.0	1.0						
	w4	0.4	0.4	0.3						
	wtot	20.1	27.5	34.9						
15	V		85.9	128.3	176.3					
	w1		33.4	51.1	71.7					
	w2		15.0	13.9	10.0					
	w3		1.5	1.7	1.9					
	w4		1.0	1.0	0.8					
	wtot		50.9	67.7	84.4					
20	V		141.6	209.5	284.9	367.8				
	w1		53.3	80.6	111.9	147.3				
	w2		26.4	28.2	26.2	20.4				
	w3		2.2	2.6	3.1	3.4				
	w4		1.9	2.2	2.2	1.9				
	wtot		83.7	113.6	143.3	173.1				
25	V		211.5	310.7	419.1	536.9	664.1			
	w1		77.9	116.8	160.7	209.7	263.8			
	w2		41.8	48.2	49.8	46.7	38.9			
	w3		3.1	3.9	4.6	5.3	5.9			
	w4		3.1	3.7	4.1	4.1	3.8			
	wtot		125.9	172.6	219.2	265.7	312.2			
30	V			431.7	579.0	737.4	907.1	1 087.9		
	w1			159.7	218.1	282.6	353.2	429.8		
	w2			73.9	80.7	81.9	77.4	67.3		
	w3			5.4	6.6	7.6	8.6	9.4		
	w4			5.8	6.5	6.9	6.9	6.6		
	wtot			244.7	311.9	379.0	446.1	513.0		
35	V				764.5	969.3	1 187.1	1 418.0	1 661.9	1 918.9
	w1				284.1	366.0	455.0	551.1	654.1	764.3
	w2				119.0	126.1	126.6	120.5	107.8	88.6
	w3				8.9	10.4	11.8	13.1	14.3	15.3
	w4				9.5	10.4	10.9	10.9	10.5	9.6
	wtot				421.5	513.0	604.3	695.6	786.7	877.8
40	V				975.6	1 232.4	1 504.2	1 790.8	2 092.4	2 408.9
	w1				358.7	459.9	569.3	686.6	812.1	945.5
	w2				164.6	179.3	186.4	186.0	178.1	162.6
	w3				11.6	13.7	15.7	17.5	19.1	20.7
	w4				13.1	14.6	15.6	16.1	16.2	15.7
	wtot				548.0	667.5	786.9	906.2	1 025.4	1 144.5
45	V					1 526.9	1 858.2	2 206.4	2 571.3	2 952.9
	w1					564.3	695.9	836.5	986.2	1 144.9
	w2					241.5	256.8	263.7	262.2	252.1
	w3					17.5	20.0	22.5	24.7	26.9
	w4					19.5	21.2	22.3	22.9	23.0
	wtot					842.7	993.9	1 145.0	1 296.0	1 446.9

(Appendix 1 - continued)
(Appendice 1 - continua)

d (cm)	h (m)	6	10	14	18	22	26	30	34	38
50	V					1 852.7	2 249.3	2 664.6	3 098.5	3 551.1
	w1					679.2	834.9	1 000.7	1 176.5	1 362.5
	w2					312.6	337.9	353.7	360.2	357.2
	w3					21.7	25.0	28.1	31.1	33.8
	w4					25.1	27.6	29.5	30.8	31.4
	wtot					1 038.6	1 225.3	1 412.0	1 598.5	1 784.9
55	V						2 677.5	3 165.6	3 674.3	4 203.4
	w1						986.3	1 179.2	1 383.1	1 598.1
	w2						429.6	456.0	472.1	477.8
	w3						30.5	34.4	38.1	41.6
	w4						34.8	37.5	39.6	41.0
	wtot						1 481.1	1 707.1	1 932.9	2 158.5
60	V						3 142.6	3 709.3	4 298.4	4 909.8
	w1						1 150.1	1 371.9	1 605.9	1 851.8
	w2						531.9	570.5	597.9	613.9
	w3						36.5	41.3	45.9	50.3
	w4						42.8	46.5	49.6	51.8
	wtot						1 761.3	2 030.3	2 299.1	2 567.8

Appendix 2 - Predicted values of volume and phytomass for the species *Abies alba* for several combinations of diameter and height.

Appendice 2 - Valori previsti del volume e della fitomassa relativi alla specie Abies alba *calcolati per diversi valori del diametro e dell'altezza.*

d (cm)	h (m)	6	9	12	15	18	21	24	27	30
10	V	26.3	36.6	47.0						
	w1	10.9	15.1	19.3						
	w2	9.5	10.0	10.5						
	w3	0.8	0.9	1.1						
	w4	0.2	0.3	0.4						
	wtot	21.4	26.3	31.3						
15	V		85.8	109.1	132.4					
	w1		32.7	42.1	51.5					
	w2		20.5	21.7	22.9					
	w3		1.1	1.4	1.7					
	w4		0.8	1.0	1.2					
	wtot		55.0	66.2	77.3					
20	V		154.8	196.2	237.6	279.0	320.3			
	w1		57.3	74.1	90.8	107.6	124.4			
	w2		35.2	37.3	39.4	41.4	43.5			
	w3		1.3	1.8	2.4	2.9	3.5			
	w4		1.5	1.9	2.2	2.6	3.0			
	wtot		95.2	115.0	134.8	154.6	174.4			
25	V			308.1	372.8	437.4	502.1	566.8		
	w1			115.1	141.4	167.6	193.8	220.0		
	w2			57.3	60.6	63.8	67.1	70.3		
	w3			2.4	3.2	4.1	5.0	5.8		
	w4			3.0	3.6	4.2	4.8	5.3		
	wtot			177.8	208.8	239.7	270.6	301.5		
30	V				538.0	631.1	724.3	817.4	910.5	1 003.6
	w1				203.1	240.9	278.6	316.4	354.1	391.9
	w2				86.5	91.2	95.9	100.6	105.2	109.9
	w3				4.3	5.5	6.8	8.0	9.2	10.5
	w4				5.2	6.1	6.9	7.8	8.6	9.5
	wtot				299.1	343.7	388.2	432.7	477.2	521.7
35	V				733.3	860.0	986.8	1 113.6	1 240.3	1 367.1
	w1				276.1	327.5	378.9	430.2	481.6	533.0
	w2				117.2	123.6	129.9	136.3	142.7	149.0
	w3				5.5	7.2	8.9	10.6	12.3	14.0
	w4				7.1	8.3	9.4	10.6	11.8	12.9
	wtot				406.0	466.5	527.1	587.7	648.3	708.9
40	V					1 124.2	1 289.7	1 455.3	1 620.8	1 786.4
	w1					427.4	494.5	561.7	628.8	695.9
	w2					160.9	169.2	177.5	185.8	194.1
	w3					9.1	11.4	13.6	15.8	18.0
	w4					10.9	12.4	13.9	15.4	16.9
	wtot					608.3	687.5	766.6	845.7	924.9
45	V					1 423.5	1 633.1	1 842.6	2 052.1	2 261.6
	w1					540.7	625.7	710.6	795.5	880.4
	w2					203.2	213.7	224.2	234.8	245.3
	w3					11.3	14.1	16.9	19.7	22.5
	w4					13.8	15.7	17.6	19.5	21.4
	wtot					769.0	869.2	969.4	1 069.5	1 169.7

(Appendix 2 - continued)
(Appendice 2 - continua)

d (cm)	h (m)	6	9	12	15	18	21	24	27	30
50	V						2 016.8	2 275.5	2 534.1	2 792.8
	w1						772.2	877.0	981.9	1 086.7
	w2						263.5	276.5	289.4	302.4
	w3						17.3	20.7	24.2	27.6
	w4						19.4	21.8	24.1	26.5
	wtot						1 072.3	1 195.9	1 319.6	1 443.3
55	V						2 440.9	2 753.9	3 066.9	3 379.9
	w1						934.1	1 061.0	1 187.9	1 314.7
	w2						318.5	334.2	349.9	365.6
	w3						20.7	24.9	29.1	33.3
	w4						23.5	26.4	29.2	32.1
	wtot						1 296.8	1 446.4	1 596.0	1 745.6
60	V						2 905.4	3 277.9	3 650.4	4 022.9
	w1						1 111.5	1 262.5	1 413.5	1 564.5
	w2						378.7	397.4	416.1	434.8
	w3						24.5	29.5	34.4	39.4
	w4						28.0	31.4	34.8	38.2

Appendix 3 - Predicted values of volume and phytomass for the species *Larix decidua* for several combinations of diameter and height.

Appendice 3 - Valori previsti del volume e della fitomassa relativi alla specie Larix decidua *calcolati per diversi valori del diametro e dell'altezza.*

d (cm)	h (m)	6	9	12	15	18	21	24	27	30
10	V	32.1	42.4	52.7	63.0	73.2				
	w1	10.9	16.6	22.4	28.1	33.9				
	w2	14.7	14.4	14.1	13.9	13.6				
	w3	0.9	1.1	1.2	1.4	1.5				
	w4	1.2	1.2	1.3	1.3	1.3				
	wtot	27.7	33.4	39.0	44.7	50.3				
15	V		82.3	105.5	128.6	151.7				
	w1		29.1	42.0	55.0	67.9				
	w2		24.1	w23.4	22.8	22.2				
	w3		0.8	1.1	1.4	1.7				
	w4		2.2	2.2	2.3	2.4				
	wtot		56.1	68.8	81.5	94.2				
20	V		137.7	178.8	219.9	261.0	302.1			
	w1		50.2	73.2	96.1	119.1	142.1			
	w2		33.3	32.2	31.0	29.9	28.8			
	w3		0.8	1.3	1.9	2.4	3.0			
	w4		3.1	3.3	3.4	3.5	3.6			
	wtot		87.3	109.9	132.4	155.0	177.5			
25	V			272.7	336.9	401.1	465.4	529.6		
	w1			115.8	151.7	187.6	223.6	259.5		
	w2			40.3	38.6	36.8	35.0	33.2		
	w3			1.8	2.6	3.5	4.3	5.2		
	w4			4.3	4.5	4.8	5.0	5.2		
	wtot			162.2	197.4	232.7	267.9	303.1		
30	V				479.6	572.1	664.6	757.1	849.6	942.1
	w1				221.6	273.4	325.1	376.8	428.6	480.3
	w2				45.4	42.8	40.3	37.7	35.2	32.6
	w3				3.7	5.0	6.2	7.4	8.7	9.9
	w4				5.8	6.1	6.4	6.7	7.0	7.3
	wtot				276.5	327.3	378.0	428.7	479.4	530.1
35	V				648.0	773.9	899.8	1 025.7	1 151.6	1 277.5
	w1				305.9	376.4	446.8	517.2	587.6	658.0
	w2				51.5	48.0	44.6	41.1	37.6	34.1
	w3				5.2	6.8	8.5	10.2	11.9	13.6
	w4				7.1	7.5	7.9	8.3	8.8	9.2
	wtot				369.7	438.8	507.8	576.8	645.9	714.9
40	V				842.1	1 006.5	1 171.0	1 335.4	1 499.9	1 664.3
	w1				404.6	496.6	588.6	680.5	772.5	864.5
	w2				56.9	52.4	47.8	43.3	38.8	34.2
	w3				7.0	9.2	11.4	13.5	15.7	17.9
	w4				8.5	9.1	9.6	10.1	10.7	11.2
	wtot				477.0	567.2	657.3	747.5	837.7	927.9
45	V				1 061.9	1 270.0	1 478.1	1 686.2	1 894.4	2 102.5
	w1				517.7	634.1	750.5	866.9	983.3	1 099.7
	w2				61.6	55.9	50.1	44.4	38.6	32.9
	w3				9.1	11.9	14.7	17.4	20.2	23.0
	w4				10.0	10.7	11.4	12.1	12.7	13.4
	wtot				598.4	712.5	826.6	940.7	1 054.9	1 169.0

(Appendix 3 - continued)
(Appendice 3 - continua)

d (cm)	h (m)	6	9	12	15	18	21	24	27	30
50	V						1 821.2	2 078.2	2 335.1	2 592.1
	w1						932.5	1 076.2	1 219.9	1 363.6
	w2						51.4	44.3	37.2	30.2
	w3						18.4	21.9	25.3	28.7
	w4						13.3	14.1	14.9	15.8
	wtot						1 015.6	1 156.5	1 297.4	1 438.3
55	V						2 200.3	2 511.2	2 822.1	3 133.1
	w1						1 134.6	1 308.5	1 482.4	1 656.3
	w2						51.7	43.1	34.6	26.0
	w3						22.7	26.9	31.0	35.2
	w4						15.3	16.3	17.3	18.3
	wtot						1 224.3	1 394.8	1 565.3	1 735.8
60	V						2 615.4	2 985.4	3 355.4	3 725.4
	w1						1 356.9	1 563.8	1 770.8	1 977.7
	w2						51.0	40.8	30.6	20.4
	w3						27.4	32.4	37.3	42.3
	w4						17.4	18.6	19.8	21.0
	wtot						1 452.8	1 655.7	1 858.5	2 061.4

Appendix 4 - Predicted values of volume and phytomass for the species *Pinus sylvestris* for several combinations of diameter and height.
Appendice 4 - Valori previsti del volume e della fitomassa relativi alla specie Pinus sylvestris *calcolati per diversi valori del diametro e dell'altezza.*

d (cm)	h (m)	6	8	10	12	14	16	18	20	22
10	V	27.2	35.5	43.7	51.9	60.1				
	w1	11.0	14.7	18.4	22.1	25.8				
	w2	5.1	6.0	6.8	7.7	8.5				
	w3	0.6	0.7	0.8	1.0	1.1				
	w4	0.3	0.3	0.4	0.4	0.5				
	wtot	16.9	21.7	26.4	31.2	35.9				
13	V	44.2	58.1	72.0	85.8	99.7				
	w1	18.6	24.9	31.1	37.4	43.6				
	w2	6.9	8.3	9.8	11.2	12.7				
	w3	0.8	1.1	1.3	1.5	1.8				
	w4	0.4	0.5	0.6	0.7	0.8				
	wtot	26.8	34.8	42.8	50.8	58.8				
16	V		86.6	107.6	128.7	149.7	170.7			
	w1		37.7	47.2	56.7	66.1	75.6			
	w2		11.3	13.5	15.7	17.9	20.1			
	w3		1.6	1.9	2.3	2.6	3.0			
	w4		0.7	0.8	1.0	1.1	1.2			
	wtot		51.3	63.4	75.6	87.7	99.9			
19	V		121.1	150.7	180.3	210.0	239.6	269.2		
	w1		53.3	66.6	79.9	93.2	106.6	119.9		
	w2		14.9	18.0	21.1	24.2	27.3	30.4		
	w3		2.1	2.6	3.1	3.6	4.1	4.6		
	w4		0.9	1.1	1.3	1.5	1.7	1.9		
	wtot		71.2	88.4	105.5	122.6	139.7	156.9		
22	V			201.2	240.9	280.6	320.3	360.0	399.7	439.4
	w1			89.3	107.2	125.0	142.9	160.8	178.7	196.5
	w2			23.3	27.5	31.6	35.8	39.9	44.1	48.2
	w3			3.5	4.1	4.8	5.5	6.1	6.8	7.5
	w4			1.5	1.7	2.0	2.3	2.5	2.8	3.1
	wtot			117.5	140.5	163.5	186.4	209.4	232.4	255.3
25	V			259.0	310.3	361.6	412.8	464.1	515.4	566.7
	w1			115.3	138.4	161.5	184.6	207.7	230.7	253.8
	w2			29.3	34.7	40.1	45.4	50.8	56.2	61.5
	w3			4.5	5.3	6.2	7.0	7.9	8.8	9.6
	w4			1.9	2.2	2.6	2.9	3.3	3.6	4.0
	wtot			151.0	180.6	210.3	239.9	269.6	299.3	328.9
28	V				388.6	452.9	517.2	581.5	645.8	710.2
	w1				173.6	202.6	231.6	260.5	289.5	318.4
	w2				42.9	49.6	56.3	63.1	69.8	76.5
	w3				6.6	7.7	8.8	9.9	10.9	12.0
	w4				2.7	3.2	3.6	4.1	4.5	4.9
	wtot				225.9	263.1	300.3	337.5	374.7	411.9
31	V				475.7	554.5	633.4	712.2	791.0	869.9
	w1				212.9	248.4	283.8	319.3	354.8	390.3
	w2				52.0	60.3	68.5	76.7	85.0	93.2
	w3				8.1	9.4	10.7	12.1	13.4	14.7
	w4				3.3	3.9	4.4	5.0	5.5	6.0
	wtot				276.3	321.9	367.5	413.1	458.7	504.3

(Appendix 4 - continued)
(Appendice 4 - continua)

d (cm)	h (m)	6	8	10	12	14	16	18	20	22
34	V					666.5	761.3	856.2	951.0	1 045.9
	w1					298.8	341.5	384.1	426.8	469.5
	w2					72.0	81.9	91.8	101.7	111.6
	w3					11.3	12.9	14.5	16.1	17.7
	w4					4.6	5.3	6.0	6.6	7.3
	wtot					386.7	441.5	496.4	551.2	606.1
37	V					788.8	901.1	1 013.5	1 125.8	1 238.1
	w1					353.8	404.4	454.9	505.5	556.1
	w2					84.8	96.5	108.2	120.0	131.7
	w3					13.4	15.2	17.1	19.0	20.9
	w4					5.5	6.3	7.0	7.8	8.6
	wtot					457.4	522.4	587.3	652.3	717.2
40	V					921.5	1 052.7	1 184.0	1 315.3	1 446.5
	w1					413.5	472.6	531.7	590.8	649.9
	w2					98.6	112.4	126.1	139.8	153.5
	w3					15.6	17.8	20.0	22.2	24.4
	w4					6.4	7.3	8.2	9.1	10.0
	wtot					534.1	610.0	686.0	761.9	837.8

Appendix 5 - Predicted values of volume and phytomass for the species *Pinus nigra* for several combinations of diameter and height.

Appendice 5 - Valori previsti del volume e della fitomassa relativi alla specie Pinus nigra *calcolati per diversi valori del diametro e dell'altezza.*

d (cm)	h (m)	6	8	10	12	14	16	18	20	22
10	V	26.2	32.6	38.9	45.3					
	w1	11.9	14.8	17.7	20.5					
	w2	2.8	2.6	2.5	2.4					
	w3	0.4	0.4	0.4	0.4					
	w4	0.5	0.5	0.5	0.5					
	wtot	15.5	18.3	21.1	23.8					
13	V	48.2	58.9	69.7	80.5					
	w1	22.6	27.4	32.3	37.2					
	w2	10.7	10.5	10.2	10.0					
	w3	1.1	1.1	1.1	1.1					
	w4	0.8	0.8	0.8	0.8					
	wtot	35.2	39.9	44.5	49.2					
16	V		92.2	108.5	124.9	141.2	157.5	173.9		
	w1		43.4	50.8	58.2	65.6	73.0	80.3		
	w2		20.4	20.0	19.7	19.3	19.0	18.6		
	w3		2.0	2.0	2.1	2.1	2.1	2.1		
	w4		1.3	1.3	1.3	1.3	1.3	1.3		
	wtot		67.0	74.1	81.2	8a8.3	95.3	102.4		
19	V		132.3	155.4	178.4	201.4	224.5	247.5		
	w1		62.7	73.1	83.5	93.9	104.3	114.8		
	w2		32.3	31.8	31.3	30.8	30.3	29.9		
	w3		3.1	3.1	3.2	3.2	3.2	3.3		
	w4		1.8	1.8	1.8	1.8	1.8	1.8		
	wtot		99.9	109.8	119.8	129.8	139.7	149.7		
22	V		179.4	210.3	241.1	272.0	302.9	333.8	364.6	
	w1		85.2	99.2	113.2	127.1	141.1	155.1	169.0	
	w2		46.2	45.6	44.9	44.3	43.6	43.0	42.3	
	w3		4.4	4.4	4.5	4.5	4.6	4.6	4.6	
	w4		2.4	2.4	2.4	2.4	2.4	2.5	2.5	
	wtot		138.3	151.7	165.0	178.4	191.8	205.1	218.5	
25	V		233.3	273.2	313.0	352.9	392.8	432.7	472.5	512.4
	w1		111.1	129.1	147.2	165.2	183.2	201.3	219.3	237.4
	w2		62.3	61.4	60.6	59.7	58.9	58.1	57.2	56.4
	w3		5.9	5.9	6.0	6.0	6.1	6.1	6.2	6.2
	w4		3.1	3.1	3.1	3.1	3.2	3.2	3.2	3.2
	wtot		182.4	199.6	216.9	234.1	251.4	268.7	285.9	303.2
28	V			344.1	394.1	444.1	494.1	544.2	594.2	644.2
	w1			162.9	185.5	208.2	230.8	253.4	276.0	298.6
	w2			79.3	78.2	77.2	76.1	75.0	74.0	72.9
	w3			7.6	7.7	7.7	7.8	7.9	7.9	8.0
	w4			3.9	3.9	4.0	4.0	4.0	4.0	4.0
	wtot			253.7	275.4	297.0	318.7	340.3	362.0	383.6
31	V			423.1	484.4	545.7	607.0	668.3	729.6	790.9
	w1			200.5	228.2	255.9	283.7	311.4	339.1	366.9
	w2			99.1	97.8	96.5	95.2	94.0	92.7	91.4
	w3			9.5	9.6	9.6	9.7	9.8	9.9	10.0
	w4			4.8	4.8	4.8	4.9	4.9	4.9	4.9
	wtot			313.9	340.4	367.0	393.5	420.1	446.6	473.1

(Appendix 5 - continued)
(Appendice 5 - continua)

d (cm)	h (m)	6	8	10	12	14	16	18	20	22
34	V				583.8	657.5	731.3	805.1	878.8	952.6
	w1				275.3	308.6	342.0	375.3	408.7	442.0
	w2				119.4	117.9	116.3	114.8	113.2	111.7
	w3				11.6	11.7	11.8	11.9	12.0	12.1
	w4				5.8	5.8	5.9	5.9	5.9	5.9
	wtot				412.2	444.1	476.0	507.9	539.8	571.8
37	V					779.8	867.1	954.4	1 041.8	1 129.1
	w1					366.1	405.6	445.1	484.7	524.2
	w2					141.2	139.4	137.5	135.7	133.9
	w3					14.0	14.1	14.3	14.4	14.5
	w4					6.9	6.9	7.0	7.0	7.0
	wtot					528.3	566.1	603.9	641.7	679.5
40	V					912.3	1 014.4	1 116.4	1 218.5	1 320.6
	w1					428.5	474.7	520.9	567.0	613.2
	w2					166.5	164.4	162.2	160.1	157.9
	w3					16.5	16.6	16.8	16.9	17.0
	w4					8.1	8.1	8.1	8.2	8.2
	wtot					619.6	663.8	708.0	752.2	796.3

Appendix 6 - Predicted values of volume and phytomass for the species *Pinus cembra* for several combinations of diameter and height.

Appendice 6 - Valori previsti del volume e della fitomassa relativi alla specie Pinus cembra *calcolati per diversi valori del diametro e dell'altezza.*

d (cm)	h (m)	6	9	12	15	18	21	24	27	30
10	V	27.9	37.0							
	w1	11.5	14.5							
	w2	4.5	4.4							
	w3	0.6	0.6							
	w4	0.3	0.4							
	wtot	16.9	19.9							
15	V		90.1	110.4	130.7					
	w1		36.4	43.2	50.0					
	w2		9.2	9.1	8.9					
	w3		2.7	2.7	2.7					
	w4		1.0	1.2	1.4					
	wtot		49.2	56.1	63.0					
20	V		164.6	200.7	236.7	272.8				
	w1		67.0	79.0	91.1	103.2				
	w2		15.8	15.6	15.4	15.2				
	w3		5.6	5.6	5.6	5.6				
	w4		1.8	2.2	2.6	3.0				
	wtot		90.1	102.4	114.7	127.0				
25	V		260.2	316.6	373.0	429.4				
	w1		106.3	125.2	144.0	162.9				
	w2		24.3	24.0	23.7	23.4				
	w3		9.3	9.3	9.3	9.4				
	w4		2.8	3.4	4.0	4.7				
	wtot		142.7	161.9	181.1	200.4				
30	V				539.6	620.9	702.1			
	w1				208.7	235.9	263.1			
	w2				33.9	33.4	33.0			
	w3				13.9	13.9	14.0			
	w4				5.8	6.7	7.6			
	wtot				262.3	290.0	317.7			
35	V				736.5	847.1	957.6	1 068.1		
	w1				285.2	322.2	359.2	396.2		
	w2				45.9	45.3	44.7	44.1		
	w3				19.3	19.3	19.4	19.4		
	w4				7.9	9.2	10.4	11.7		
	wtot				358.3	396.0	433.7	471.4		
40	V				963.7	1 108.1	1 252.5	1 396.8		
	w1				373.4	421.7	470.0	518.3		
	w2				59.7	59.0	58.2	57.5		
	w3				25.5	25.6	25.6	25.7		
	w4				10.4	12.0	13.6	15.2		
	wtot				469.0	518.3	567.5	616.7		
45	V				1 221.1	1 403.9	1 586.6	1 769.3	1 952.1	
	w1				473.4	534.5	595.7	656.8	718.0	
	w2				75.4	74.4	73.5	72.5	71.6	
	w3				32.6	32.7	32.7	32.8	32.8	
	w4				13.2	15.2	17.3	19.3	21.4	
	wtot				594.5	656.8	719.1	781.4	843.7	

(Appendix 6 - continued)
(Appendice 6 - continua)

d (cm)	h (m)	6	9	12	15	18	21	24	27	30
50	V					1 734.5	1 960.1	2 185.7	2 411.3	2 636.9
	w1					660.6	736.1	811.6	887.1	962.6
	w2					91.8	90.6	89.4	88.2	87.1
	w3					40.6	40.7	40.7	40.8	40.9
	w4					18.8	21.3	23.8	26.4	28.9
	wtot					811.7	888.6	965.5	1 042.5	1 119.4
55	V					2 099.9	2 372.9	2 645.8	2 918.8	3 191.8
	w1					799.9	891.3	982.6	1 074.0	1 165.3
	w2					110.9	109.5	108.1	106.6	105.2
	w3					49.3	49.4	49.5	49.6	49.7
	w4					22.7	25.8	28.9	31.9	35.0
	wtot					982.9	1 075.9	1 169.0	1 262.1	1 355.2
60	V					2 500.1	2 825.0	3 149.8	3 474.7	3 799.6
	w1					952.5	1 061.3	1 170.0	1 278.7	1 387.4
	w2					131.8	130.2	128.5	126.8	125.1
	w3					58.9	59.0	59.1	59.2	59.3
	w4					27.1	30.7	34.4	38.0	41.6
	wtot					1 170.3	1 281.1	1 391.9	1 502.6	1 613.4

Appendix 7 - Predicted values of volume and phytomass for the species *Fagus sylvatica* for several combinations of diameter and height.
Appendice 7 - Valori previsti del volume e della fitomassa relativi alla specie Fagus sylvatica *calcolati per diversi valori del diametro e dell'altezza.*

d (cm)	h (m)	6	9	12	15	18	21	24	27	30
10	V	28.7	38.0	47.4	56.7					
	w1	16.8	22.7	28.6	34.4					
	w2	8.9	8.3	7.7	7.1					
	w3	(0.0)	(0.0)	(0.0)	0.1					
	w4	0.6	0.5	0.5	0.5					
	wtot	(26.3)	(31.5)	(36.8)	42.1					
15	V		95.6	116.6	137.6	158.5	179.5			
	w1		55.7	68.9	82.1	95.3	108.5			
	w2		25.7	24.3	23.0	21.7	20.4			
	w3		(0.0)	0.2	0.6	0.9	1.3			
	w4		2.7	2.6	2.5	2.5	2.4			
	wtot		(84.1)	96.1	108.3	120.4	132.6			
20	V			213.5	250.8	288.1	325.4			
	w1			125.4	148.9	172.3	195.8			
	w2			47.6	45.3	43.0	40.6			
	w3			0.7	1.3	1.9	2.5			
	w4			5.5	5.4	5.3	5.2			
	wtot			179.2	200.9	222.5	244.1			
25	V			338.1	396.4	454.7	512.9			
	w1			198.0	234.7	271.4	308.0			
	w2			77.6	73.9	70.3	66.6			
	w3			1.2	2.2	3.1	4.1			
	w4			9.3	9.1	8.9	8.7			
	wtot			286.1	319.9	353.7	387.5			
30	V			490.4	574.3	658.2	742.1			
	w1			286.8	339.6	392.4	445.2			
	w2			114.2	108.9	103.6	98.4			
	w3			1.9	3.3	4.7	6.0			
	w4			13.9	13.6	13.3	13.1			
	wtot			416.8	465.4	514.1	562.7			
35	V				784.6	898.8	1 013.0	1 127.3		
	w1				463.6	535.5	607.3	679.2		
	w2				150.2	143.1	135.9	128.8		
	w3				4.6	6.5	8.3	10.2		
	w4				19.0	18.6	18.2	17.8		
	wtot				637.4	703.6	769.8	836.0		
40	V				1 027.2	1 176.4	1 325.6	1 474.8		
	w1				606.6	700.5	794.4	888.3		
	w2				197.9	188.6	179.3	169.9		
	w3				6.1	8.6	11.0	13.4		
	w4				25.1	24.6	24.1	23.7		
	wtot				835.8	922.3	1 008.8	1 095.3		
45	V					1 491.0	1 679.8	1 868.7	2 057.5	
	w1					887.6	1 006.4	1 125.2	1 244.0	
	w2					240.2	228.4	216.5	204.7	
	w3					10.9	14.0	17.1	20.1	
	w4					31.5	30.9	30.2	29.6	
	wtot					1 170.2	1 279.6	1 389.1	1 498.5	

(Appendix 7 - continued)
(Appendice 7 - continua)

d (cm)	h (m)	6	9	12	15	18	21	24	27	30
50	V					1 842.7	2 075.8	2 308.9	2 542.0	2 775.1
	w1					1 096.7	1 243.4	1 390.0	1 536.7	1 683.4
	w2					297.8	283.2	268.6	254.0	239.4
	w3					13.5	17.3	21.1	25.0	28.8
	w4					39.1	38.4	37.6	36.9	36.1
	wtot					1 447.2	1 582.3	1 717.4	1 852.5	1 987.7
55	V					2 231.3	2 513.4	2 795.4	3 077.5	3 359.5
	w1					1 327.7	1 505.2	1 682.7	1 860.2	2 037.7
	w2					361.5	343.9	326.2	308.5	290.9
	w3					16.5	21.1	25.7	30.3	34.9
	w4					47.6	46.7	45.8	44.8	43.9
	wtot					1 753.3	1 916.8	2 080.3	2 243.9	2 407.4
60	V					2 657.0	2 992.6	3 328.3	3 663.9	3 999.6
	w1					1 580.8	1 792.1	2 003.3	2 214.5	2 425.8
	w2					431.3	410.3	389.3	368.3	347.2
	w3					19.6	25.1	30.6	36.1	41.5
	w4					56.9	55.8	54.7	53.6	52.5
	wtot					2 088.7	2 283.3	2 477.8	2 672.4	2 867.0

Appendix 8 - Predicted values of volume and phytomass for the group *Ostrya carpinifolia* and other similar tree species for several combinations of diameter and height.
Appendice 8 - Valori previsti del volume e della fitomassa relativi al gruppo Ostrya carpinifolia *e altre specie simili calcolati per diversi valori del diametro e dell'altezza.*

d (cm)	h (m)	4	6	8	10	12	14	16	18	20
10	V	27.5	32.4	37.3	42.2	47.1				
	w1	21.9	24.3	26.7	29.1	31.5				
	w2	15.5	14.1	12.8	11.4	10.0				
	w3	0.5	0.4	0.4	0.3	0.2				
	w4	0.5	0.6	0.7	0.8	0.9				
	wtot	38.4	39.5	40.5	41.6	42.6				
13	V	50.3	58.6	66.9	75.2	83.4	91.7			
	w1	40.2	44.3	48.4	52.4	56.5	60.6			
	w2	26.0	23.7	21.4	19.0	16.7	14.4			
	w3	0.9	0.8	0.7	0.6	0.4	0.3			
	w4	0.9	1.1	1.2	1.4	1.5	1.7			
	wtot	68.1	69.9	71.6	73.4	75.2	77.0			
16	V		91.6	104.1	116.7	129.2	141.7	154.3		
	w1		69.5	75.7	81.8	88.0	94.2	100.3		
	w2		35.8	32.2	28.7	25.2	21.7	18.1		
	w3		1.2	1.1	0.9	0.7	0.5	0.5		
	w4		1.7	1.9	2.1	2.4	2.6	2.9		
	wtot		108.2	110.9	113.6	116.3	119.0	121.7		
19	V			149.1	166.8	184.4	202.1	219.8		
	w1			108.7	117.3	126.0	134.7	143.4		
	w2			45.4	40.4	35.4	30.4	25.4		
	w3			1.5	1.3	1.1	0.8	0.6		
	w4			2.7	3.0	3.4	3.7	4.1		
	wtot			158.3	162.1	165.9	169.7	173.5		
22	V			201.8	225.4	249.1	272.8	296.5		
	w1			147.3	158.9	170.6	182.2	193.9		
	w2			60.7	54.0	47.4	40.7	34.0		
	w3			2.1	1.8	1.4	1.1	0.8		
	w4			3.6	4.1	4.6	5.0	5.5		
	wtot			213.7	218.8	223.9	229.0	234.1		
25	V				292.7	323.3	353.9	384.5	415.1	
	w1				206.6	221.6	236.7	251.7	266.8	
	w2				69.7	61.1	52.5	43.8	35.2	
	w3				2.3	1.9	1.5	1.0	0.6	
	w4				5.3	5.9	6.5	7.1	7.7	
	wtot				283.9	290.5	297.1	303.7	310.3	
28	V					407.0	445.4	483.7	522.1	
	w1					279.2	298.1	316.9	335.8	
	w2					76.6	65.7	54.9	44.8	
	w3					2.4	1.9	1.3	0.8	
	w4					7.4	8.2	8.9	9.6	
	wtot					365.6	373.8	382.1	390.4	
31	V					500.1	547.1	594.2	641.2	
	w1					343.3	366.4	389.6	412.7	
	w2					93.8	80.5	67.3	54.0	
	w3					3.0	2.3	1.6	1.0	
	w4					9.1	10.0	10.9	11.8	
	wtot					449.2	459.3	469.4	479.5	

(Appendix 8 - continued)
(Appendice 8 - continua)

d (cm)	h (m)	4	6	8	10	12	14	16	18	20
34	V					602.7	659.3	715.9	772.5	829.1
	w1					413.9	441.7	469.6	497.4	525.2
	w2					112.8	96.8	80.9	64.9	49.0
	w3					3.6	2.8	2.0	1.2	0.4
	w4					11.0	12.1	13.2	14.2	15.3
	wtot					541.2	553.4	565.6	577.7	589.9
37	V					714.7	781.7	848.8	915.8	982.8
	w1					491.0	524.0	556.9	589.9	622.8
	w2					133.5	114.6	95.7	76.8	58.0
	w3					4.2	3.3	2.4	1.4	0.5
	w4					13.0	14.3	15.6	16.9	18.2
	wtot					641.8	656.2	670.6	685.0	699.5
40	V					836.2	914.6	992.9	1,071.2	1,149.6
	w1					574.7	613.2	651.7	690.2	728.7
	w2					156.0	133.9	111.8	89.8	67.7
	w3					5.0	3.9	2.8	1.7	0.6
	w4					15.2	16.7	18.2	19.7	21.2
	wtot					750.9	767.7	784.6	801.4	818.3

Appendix 9 - Predicted values of volume and phytomass for the group *Castanea sativa* and other similar tree species for several combinations of diameter and height.

Appendice 9 - Valori previsti del volume e della fitomassa relativi al gruppo Castanea sativa *e altre specie simili calcolati per diversi valori del diametro e dell'altezza.*

d (cm)	h (m)	6	8	10	12	14	16	18	20	22
10	V	25.8	31.4	36.9	42.5	48.1				
	w1	13.2	16.1	18.9	21.8	24.6				
	w2	12.1	11.1	10.0	9.0	8.0				
	w3	0.2	0.3	0.5	0.6	0.8				
	w4	1.4	1.5	1.7	1.8	2.0				
	wtot	26.8	29.0	31.1	33.3	35.4				
13	V	45.3	54.7	64.1	73.6	83.0				
	w1	22.2	27.0	31.8	36.7	41.5				
	w2	20.3	18.6	16.9	15.2	13.5				
	w3	0.3	0.5	0.8	1.1	1.3				
	w4	2.4	2.6	2.9	3.1	3.4				
	wtot	45.2	48.8	52.5	56.1	59.7				
16	V	69.9	84.2	98.4	112.7	127.0	141.2			
	w1	33.5	40.8	48.1	55.4	62.7	70.1			
	w2	30.8	28.2	25.6	23.0	20.4	17.8			
	w3	0.4	0.8	1.2	1.6	2.0	2.4			
	w4	3.7	4.0	4.4	4.8	5.2	5.6			
	wtot	68.4	73.9	79.4	84.9	90.4	95.9			
19	V		119.7	139.8	159.9	180.1	200.2			
	w1		57.5	67.8	78.1	88.4	98.7			
	w2		39.7	36.1	32.4	28.7	25.1			
	w3		1.2	1.7	2.3	2.9	3.4			
	w4		5.7	6.3	6.8	7.4	7.9			
	wtot		104.1	111.8	119.6	127.3	135.1			
22	V		161.3	188.3	215.3	242.3	269.3			
	w1		77.0	90.8	104.6	118.4	132.3			
	w2		53.2	48.3	43.4	38.5	33.6			
	w3		1.6	2.3	3.1	3.8	4.6			
	w4		7.7	8.5	9.2	9.9	10.6			
	wtot		139.5	149.9	160.3	170.7	181.1			
25	V		209.0	243.9	278.7	313.6	348.4	383.3	418.1	453.0
	w1		99.3	117.2	135.0	152.9	170.7	188.6	206.4	224.3
	w2		68.7	62.4	56.0	49.7	43.4	37.0	30.7	24.3
	w3		2.0	3.0	4.0	4.9	5.9	6.9	7.9	8.8
	w4		10.0	10.9	11.9	12.8	13.7	14.7	15.6	16.6
	wtot		180.1	193.5	206.9	220.3	233.8	247.2	260.6	274.0
28	V		262.8	306.5	350.3	394.0	437.7	481.4	525.1	568.8
	w1		124.5	146.9	169.3	191.7	214.1	236.5	258.9	281.3
	w2		86.2	78.2	70.3	62.3	54.4	46.4	38.5	30.5
	w3		2.5	3.8	5.0	6.2	7.4	8.7	9.9	11.1
	w4		12.6	13.8	14.9	16.1	17.3	18.4	19.6	20.8
	wtot		225.8	242.7	259.5	276.3	293.2	310.0	326.9	343.7
31	V				429.9	483.5	537.1	590.7	644.2	697.8
	w1				207.5	235.0	262.4	289.9	317.3	344.8
	w2				86.1	76.4	66.6	56.9	47.1	37.4
	w3				6.1	7.6	9.1	10.6	12.1	13.6
	w4				18.3	19.8	21.2	22.6	24.1	25.5
	wtot				318.1	338.7	359.3	380.0	400.6	421.3

(Appendix 9 - continued)
(Appendice 9 - continua)

d (cm)	h (m)	6	8	10	12	14	16	18	20	22
34	V					582.1	646.6	711.0	775.5	839.9
	w1					282.6	315.6	348.6	381.7	414.7
	w2					91.8	80.1	68.4	56.7	45.0
	w3					9.2	11.0	12.8	14.6	16.4
	w4					23.8	25.5	27.2	29.0	30.7
	wtot					407.4	432.2	457.0	481.9	506.7
37	V					689.8	766.1	842.5	918.8	995.1
	w1					334.6	373.7	412.8	451.9	491.0
	w2					108.8	94.9	81.0	67.1	53.2
	w3					10.8	13.0	15.1	17.3	19.4
	w4					28.2	30.2	32.3	34.3	36.4
	wtot					482.4	511.8	541.2	570.6	600.0
40	V					806.6	895.8	985.1	1 074.3	1 163.5
	w1					391.0	436.8	482.5	528.2	573.9
	w2					127.1	110.9	94.6	78.4	62.2
	w3					12.7	15.2	17.7	20.2	22.7
	w4					33.0	35.4	37.7	40.1	42.5
	wtot					563.8	598.1	632.5	666.9	701.3