LIFE GoProForMED

Project 101074738 - LIFE21-NAT-IT-LIFE GOPROFOR MED

Improvement of the conservation status of forest habitats in the Mediterranean Biogeographical Region applying restoration and conservation techniques and *Close to Nature* management

Defining the degree of disturbance in Mediterranean forests

Methodological framework and monitoring tools

WP2 - Assessment of the conservation status of target forest habitats

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Prediction of degree of disturbance

All ecosystems are subject to more or less frequent events that alter their structure and function (referred to in ecology as 'disturbances'). If the frequency of relevant disturbances is very low (i.e. every few centuries), phytocoenoses can evolve into very somatically-chronologically complex communities, with species/individuals of different sizes coexisting on the same area. These communities are often referred to as old-growth forests. The attainment of such a condition, however dynamic, may be due to the fact that the community as a whole grows as long as the individuals comprising it still have available resources to utilise. The fact that resources are always finite (e.g. rainfall corresponds to a specific annual amount) should determine that the community's growth is also finite and that therefore, at a certain point, the community saturates all available resources so that the processes of birth-fixation of carbon are equivalent to those of mortality-degradation.

From a theoretical point of view, the interesting thing is that it is possible to predict, using the tools of statistical mechanics with a simplified system, the distribution of the size of individuals in a community that is able to optimise the use of resources (light, water, etc.) in the same way as in a state of forest senescence.

The proposed model (H- Model, Simini et al 2010, Anfodillo et al 2013) represents an application of the allometric approach that allows us to quantify how 'distant' the current structural condition of the forest is from that of maximum theoretical functionality. It is a general and universal tool that can be applied to all forests and, therefore, theoretically also to Mediterranean forests. A further simplification is that the model is species-aspecific so that only the resource consumption rate of an individual is important but not to which species it belongs.

The aim of the manual is to provide the theoretical and practical tools for a correct survey of the current state of the forests involved in the project and to transfer the relevant field data to the TESAF research unit - University of Padua. The latter will be in charge of the data processing of the 9 stations involved in the LIFE project:

- Tuscany (IT) Site IT5180011- Pascoli montani e cespuglieti del Pratomagno
- Catalunya (ES) Site ES5120001 - Alta Garrotxa-Massís de les Alberes, forest of Muntanya de les salines, fucimanya i balló
- Catalunya (ES) Site ES5120050 - Litoral del Baix Empordà, forest of Paratge i pla de castell
- Catalunya (ES) Site ES5140008 - Muntanyes de Prades, forest of Poblet
- Catalunya (ES) Site ES5140008 - Muntanyes de Prades, forest of Plans i baridana
- Kentriki Makedonia (GR) Site GR1220009 - Limnes koroneias - volvis, stena rentinas kai evryteri periochi
- Provence-Alpes-Côte d'Azur (FR) Site FR9301585- Massif du Luberon
- Provence-Alpes-Côte d'Azur (FR) Site FR9301570 - Préalpes de Grasse
- Provence-Alpes-Côte d'Azur (FR) Site FR9302007 - Valensole

The ultimate goal is to determine the degree of deviation from the respective potential of the forests at the different sites in order to be able to reflect on management strategies with a better knowledge of the current state of the structure.

Theoretical framework of the H-model

The H-model is an allometric model, developed at the University of Padua and based on statistical mechanics principles. The-H model predicts the potential distribution of the frequency of tree individuals per size class in a forest at its maximum state of available resource utilisation (Anfodillo et al., 2013; Sellan et al., 2017; Simini et al., 2010). The survey of the tree layer in a given target forest as a function of comparison with the H-model allows us to determine the degree of deviation between the current situation and its maximum functional potential. The model is based on four fundamental assumptions that are briefly summarised below, the first two concerning the single tree, the second two the entire forest:

Single tree

1.

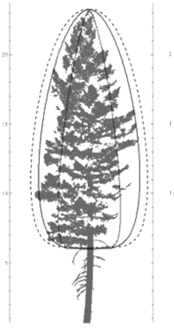
Crown volume depends on height

$$r_{cro} \propto h^H$$

2.

The metabolic rate of the tree (i.e. how many resources are used) varies with the crown volume

$$B \propto V_{cro} \propto h^{a(1+2H)}$$



Forest

3.

The forest optimises resources by using them all to the maximum. Crowns tend to fill all available space. The forest's metabolism is proportional to the volume filled.

$$B_{tot} \propto V_{tot} \propto A_{tot} h_c$$

4.

The size distribution of trees is not a pure power law, but is **finite (finite size-scaling)**, i.e. **it has a limit to the maximum height**. *The curvature cutoff represents the maximum height h**c***

In summary, the application process of the model to a forest can be schematised in three basic steps:

1. **Define how the shape of the crown changes as a function of height.** Resource utilisation on an individual level (metabolic rate) is expressed by the crown volume. It is therefore necessary to define crown volume development for the target species. The change in crown volume as a function of height is then measured. In particular, the crown radius r_{cro} s proportional to the tree height h and varies with the latter according to an exponent H during ontogeny.

$$r_{cro} \propto h^H$$

The individual's metabolic rate B scales isometrically with the crown volume V_{cro} i.e. with the total leaf area which is a function of the individual's photosynthetic capacity:

$$B \propto V_{cro} \propto r_{cro}^2 \propto h^{1+2H}$$

The isometry between metabolic activity and leaf area is preserved during ontogeny, i.e. proportionality is preserved with height development. It can be approximated that resource utilisation depends on the volume of foliage, which in turn is estimated simply as a cylinder (but any other shape would be possible and the results would not change):

$$V_{cro} \propto \, I_{cro} \times r_{cro}^2$$

where I_{cro} is the height of the crown and in turn depends on the total height of the individual (Sellan et al. 2017), and thus we obtain the following relationships:

$$I_{cro} \propto \, h^a$$

$$B \propto V_{cro} \propto h^{a(1+2H)}$$

This variation expresses the rate of resource consumption per tree. The exponent *a(1+2H)* expresses the rate of change between the volume and the total height of the tree and is also the indicator of resource use at the individual level for the species under investigation.

It has been shown that the metabolism of an individual tree depends on the volume of the individual crown, thus the metabolism of the entire forest B_{tot} depends on the total leaf area of the forest. Under optimal conditions, it is assumed that the leaves are the maximum amount compatible with the available resources and that they occupy a volume proportional to the forest area A_{tot} for the value of the stature where the power law representation h_c applies:

$$B_{tot} \propto V_{tot} \propto \, A_{tot} h_c$$

2. **Application of the H model, i.e. defining the probability of diametric distribution of the forest consisting of trees with the metabolic proportions described above.**
When this condition occurs in which the metabolic leaf area is the maximum compatible with the resources present, it has been shown that the probability of distribution of the magnitudes follows the following relationship:

$$P(h) \propto B^{-1} \propto V_{cro}^{-1} \, \propto h^{-a(1+2H)}$$

This relationship is guided by the height parameter h, which is often not easy to measure systematically in the forest. It is therefore necessary to resort to a conversion where the diameter at the base (r) is used instead of the height as a synthetic reference parameter:

$$h \propto r^{b}$$

and we obtain that the probability distribution of diameters is defined by:

$$P(r) = P(h)\frac{dh}{dr} \propto r^{-ba(1+2H)}\frac{r^{b}}{r} \propto r^{-ba(1+2H)+b-1}$$

3. **Comparison of the potential curve with the actual curve.** An inventory of the tree layer is prepared including the regeneration by means of diametric relascopic areas and the real diametric distribution curve at the survey site is defined. Once the actual structure is identified, it is compared with the potential structure defined in step 2.

Materials and methods

Field data collection

Teams and working time. At least 60 test plots are recommended for monitoring a forest type. Each test plot includes a relascopic survey and a transect survey for regeneration. In addition, a survey is required to identify crown volume parameters by measuring approximately 80-100 trees from a height of 2 m to the maximum detectable height. With a team of 4 people it is possible to carry out the work in 7 days, depending on the weather conditions, accessibility of the site and slopes.

Tools

- Bitterlich Relascope, selection on strip no. 1
- Metric string with conversion to diameters
- Tree calipter (80 cm)
- Gauge
- Rod of 1 metre length
- Rope of 10 metres length
- Hypsometer (ex. TruPulse)
- Sheet with random number (or on-site selection of test areas)
- Compass
- Survey fieldsheets

- Forest technical maps

Survey of relascopic areas and regeneration transects

Identification of sampling points

Sampling points should be selected to be representative of the average condition of the forest to be assessed. If there has been differential past forest management on the areas being monitored it would be appropriate to divide the sampling for these areas as if to consider them two different forests. For example, if we have a holm oak high forest (*Q.ilex*) in transition from coppice, together with a natural holm oak forest, it is suggested to treat these two areas as belonging to two different forests. This will make it possible to identify the degree of disturbance of either formation and to target management specifically for each.

Often Mediterranean forests are areas where there are numerous disturbances such as fire or grazing by both domestic and wild animals such as the wild boar (*Sus scrofa meridionalis*) and the mouflon (*Ovis aries musimon*) found in Sardinia. As a result, forest cover can often be sparse or discontinuous (*patchy*). In patch situations, it is possible to place forest stand surveys where the latter is continuous. In this case, the assessment of the degree of forest disturbance will refer to the forested patches. If, on the other hand, we select the entire forest including the grazed or fire-prone patches (i.e. currently grassland or shrubland), we will have a representative description of the entire system including the disturbances listed above. At this point we will have to consider whether to reconsider the area as silvo-pastoral in the case of grazing.

There should be about 60 survey areas per forest type. Their detection should be randomised. Randomisation can be done:

- with a selection of GPS points falling within the selection area, on remote or on site. In the first case, field adjustments will be necessary to avoid inaccessible areas or to set up an exclusive selection based on the DTM;
- with a simple numerical fieldsheet presenting random numbers to place the sampling areas. Three sets of numbers were generated for this purpose: one from 1 to 150, the other two from 1 to 360. The first represents the number of steps to reach the centre of each sample area. In this case, the starting point is always the centre of the previous test area. The second series gives the indication of degrees relative to magnetic north. The third series determines the direction, always in degrees, relative to magnetic north towards which the transect survey for regeneration is to be carried out. The related sheet is provided in the appendix to this manual as **fieldheet A.**

Sampling method for diametric relascopic areas (trees >2 m high)

Having randomly identified the central point of the survey area, a virtual diametric relascope area is sampled using the Bitterlich relascope. The Bitterlich relascope has three fundamental numbering strips corresponding to $\Phi = 1$, $\Phi = 2$ and $\Phi = 3$. For these measurements, the strip of 1, located on the far left of the instrument, will be used (Figure 2).

Figure 2. Photo of the inner viewfinder of the Bitterlich relascope. Strip no. 1 on the left.

The choice of numbering factor leads to determining the size of the virtual test areas. The adoption of Φ = 1 results in tendentially large areas and a hopefully accurate result. To determine whether a tree is included in a virtual area, the stem section at 1.30 m above ground (DBH) is displayed:

- DBH > Φ1. If the section at 1.30 is wider than the strip of 1, the tree is considered to be part of the virtual area and its diameter is measured at the base of the trunk and at 1.30 m using a metric string for the circumference or a tree calipter for the diameter. The measurement is given an integer value of 1.
- DBH < Φ1. The section at 1.30 is narrower than the strip of 1, the tree is not included in the test area.
- DBH = Φ1. If the trunk section is as wide as the strip of 1, the tree is considered to be 'boundary' and therefore the two orthogonal diameters are measured and a value of 0.5 is assigned.

In the event that the view is obscured by other trees closer by, it is possible to make small shifts or implement an alternative strategy in collaboration with the colleague in charge of measuring diameters. Specifically, the measurement of the trunk that is not visible with the relascope from the centre of the test area can be taken with the tree calipter and then shown to the relascopist outside the obstacle that precludes the view of the tree. It is recommended, however, that care be taken not to set back the position of the tree calipter in relation to the actual trunk in order to avoid creating errors by, for example, dropping the tree at the edge of the survey area.

In contrast to measurements for dendrometric and forest production purposes, it is necessary to report diameters in 1 cm width classes to allow greater precision in estimating the exponent of the diametric curve.

In the progression of the measurements at 360° from the point where the surveyor stands, it is recommended to always mark with chalk or forestry marker all the trees counted and to which a value (1 or 0.5) and a diameter have been attributed, so as not to incur in double measurements.

Subsequently, the basimetric area (gi) for each diameter class and the ratio between the value belonging to strip 1 of the Bitterlich relascope (Φ = 1) and gi will be calculated to obtain the number of trees per hectare.

Sampling method for 10 m x 1 m transects (trees <2 m high)

Apart from special cases of very small trees belonging to the regeneration that are very close to the target, the relascope tends to exclude all small trees. For this reason, a survey of the regeneration and trees below a height of 2 m is carried out.

Taking the centre of each plot as a reference, using the random method and a compass, the direction (in degrees N) towards which to place the 10 m long by 1 m wide transect for measuring the regeneration is chosen (Figure 3). The number of the regeneration transect to be entered on the survey sheet is the same as the number of the relascopic area in which it is located, preceded by the letter R. Example: Relascopic area '61', regeneration transect 'R61'.

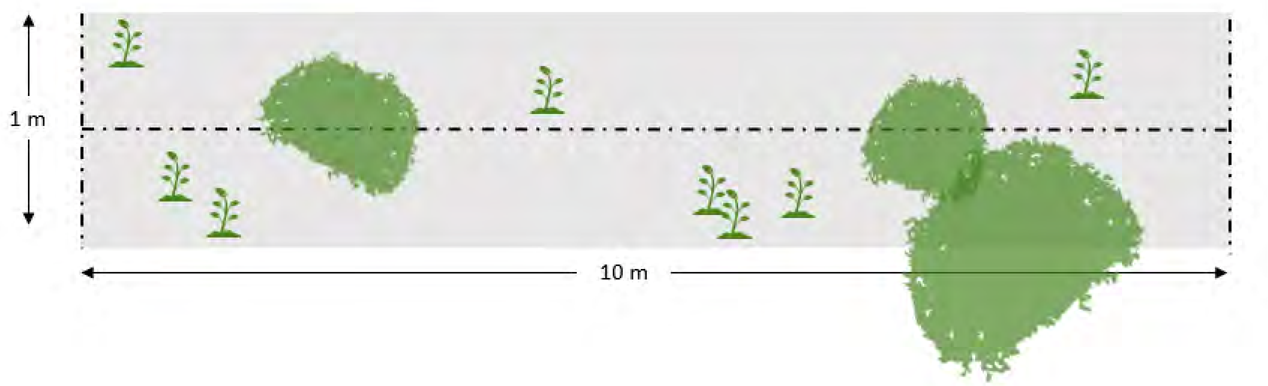


Figure 3. Example of a transect for regeneration.

Within the strip defined by the transect, all trees systematically falling within it are surveyed. The following cases can be simplified:

1. In the case where we have single-trunk trees < 2 m in height, the diameter at the base is measured using a caliper and the species is reported (indicating the scientific name).
2. In the case where such trees are represented by extremely young regeneration with diameters <=1 cm, it is sufficient to simply report the total number of individuals.
3. In the event that the trees falling within the transect are individuals with a cushion-like shrub habit (i.e. it is not possible to identify a main stem whose diameter at the base can be measured), the following parameters will be measured and then the volume of the crown will be verified and reported to the model:

- Total tree height
- Length of the longest branch
- Length of the branch positioned at 180° to the longest one

In this case, the operator is also asked to visually estimate (and report in the fieldsheet), in addition to the species, the percentage of the foliage falling within the transect (e.g. 50%, the value 0.5 is reported). If the crown of the shrub falls completely within the transect, it will not be necessary to add any specification.
In fact, Mediterranean forests can have areas with an abundance of shrubs of various species often belonging to the maquis (Figure 4). In these cases the height of the first living branch almost always corresponds to the ground and sometimes it may not be possible to detect the diameter at the base of the trunk either because

it cannot be identified as the primary trunk or because it is unreachable for measurement due to excessive thorniness (e.g. *Juniperus*).
In such a case, in the section of the table dedicated to the diameter at the base, the box with 'n.d' should be ticked. (not detectable). If the total crown area of the shrub falls partially outside the transect area (see Figure 3), only the total base area of the shrub crown projection can be reported in a simplified manner (approximate to the closest geometric shape) and its height (Figure 5).

Figure 4. Examples of field surveys. On the left, a shrub (*Rosmarinus officinalis*) falls partially within the transect delimited by the tree calipter rod.

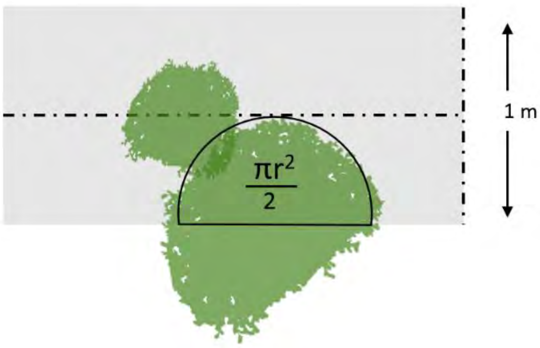


Figure 5. Example of a shrub partially falling within the regeneration transect. In this case, the area is approximated to the area of a semicircle as indicated by the equation.

If the seedlings have a diameter of <1 cm, it will be sufficient to count the total number of individuals with these characteristics falling within the transect area, omitting the survey of all the other parameters described above.

Survey of crown volume

Approximately 80-100 trees must be sampled across the size range with at least five replications for each height class. The height classes can be subdivided by 2 m as shown in Table 1 and Sheet B for the height survey. It is desirable that these individuals are evenly distributed within the total survey area and not confined to only a few relascopic areas.

It is possible that the stand consists of several different species (e.g. *Castanea* and **Fagus**). In such a case, the crown volume survey may include individuals of both species if both are present. Individuals of one species are likely to be more present in smaller height classes and individuals of the other species are more likely to be present at greater heights. The survey will be descriptive of the crown volumes of the stand, i.e. the use of space by the component species. It is not necessary to make separate species-specific sheets, but simply indicate the species in the appropriate column of Sheet B

Table 1. Field survey sheet for surveying heights

range h	H (m)	DBH (cm)	DB (cm)	H 1°living branch	R1 (m)	R2 (m)	R1 @½l_{cro}	R2 @½l_{cro}
0-2mt	1.2		5	0	1.3	0.25		
	0.9		4	0	0.45	0.15		
	1.9		6	1.1	0.4	0.55		
	1.8		5	1.1	1.4	0.8		
	1.3		3	0.8	0.7	0.3		
	1.9		5	1.6	1.1	1.2		
	1.5	3	4	0.6	0.4	0.3		
	1.6	3	4	0.7	0.4	0.2		
2-4mt	2.2		6	1.4	1.3	1.1		
	3.6	5	9	2.1	0.8	0.5		
	3.6	6	9	1.7	1.1	0.6		
	3.7	4	4	1.5	0.9	0.7		

The survey is carried out with two operators using a laser sensor (Trupulse) for the measurements of total tree height, height of the first living branch from the ground, crown radii, while diameters are alternately measured with a tree calipter or diametric string at a height of 1.30 m and at the base, avoiding the presence of buttresses.

The crown lenght l_{cro} is derived by the difference between the total height and the height of the first living branch from the ground. The crown radius is derived from the average of the measured crown radii to define the base area of the cylinder in which the total leaf area of the tree is contained.

For the crown radii, it is important that the two longest radii at the base oriented at 180° to each other are surveyed. In cases where the crowns are strongly asymmetrical to each other in relation to the main trunk or in the vertical direction, we suggest that the two radii at the middle of the crown length are also surveyed.

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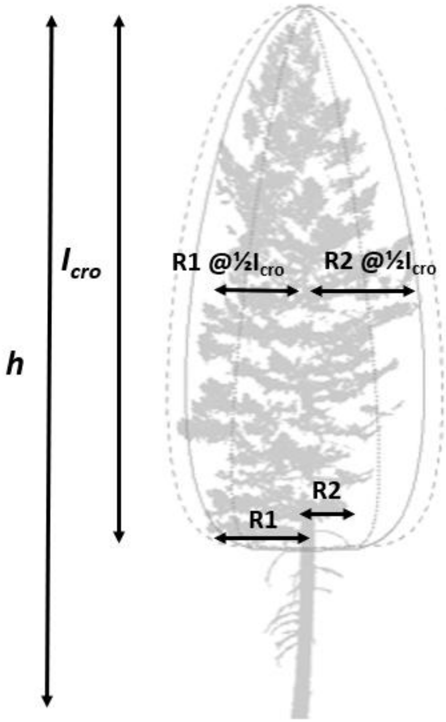


Figure 1. Explanatory figure of the measurements required to assess the crown volume in a case of a partially asymmetrical crown with the survey of two opposite crown radii relative to living branches at the base and two crown radii in the middle of the crown length

Data processing and expected results

Sharing of field data with the UniPD-TESAF support group

For each site involved in data collection (Table 2), a contact person will be identified who will be responsible for transmitting the data collected in the field. Details will be discussed during a special coordination meeting.

The data will be collected by the research group of the University of Padua, which will carry out the processing.

For information and clarification, in addition to the DREAM staff, please contact Gaia Pasqualotto at: gaia.pasqualotto@unipd.it.

Table 2. Identification of sites belonging to the project

Site name	ID
Tuscany (IT) Site IT5180011- Pascoli montani e cespuglieti del Pratomagno	IT5180011
Catalunya (ES) Site ES5120001 - Alta Garrotxa-Massís de les Alberes, forest of Muntanya de les salines, fucimanya i balló	ES5120001
Catalunya (ES) Site ES5120050 - Litoral del Baix Empordà, forest of Paratge i pla de castell	ES5120050
Catalunya (ES) Site ES5140008 - Muntanyes de Prades, forest of Plans i baridana	ES5140008
Catalunya (ES) Site ES5140008 - Muntanyes de Prades, forest of Poblet	ES5140008
Provence-Alpes-Côte d'Azur (FR) Site FR9301585- Massif du Luberon	FR9301585
Kentriki Makedonia (GR) Site GR1220009 - Limnes koroneias - volvis, stena rentinas kai evryteri periochi	GR1220009
Provence-Alpes-Côte d'Azur (FR) Site FR9301570 - Préalpes de Grasse	FR9301570
Provence-Alpes-Côte d'Azur (FR) Site FR9302007 - Valensole	FR9302007

Results – June 2023

An example is illustrated below for the case study of the State Forest of Montes (NU, Sardinia, Italy). The forest survey activity took place from 6 to 16 June 2023 with the support of Fo.Re.STAS personnel.

The survey areas were carried out on the areas belonging to the forest category Holm Oak Forests identified in the Forest Categories Map attached to the forest plan of Supramonte (Region of Sardinia, 2014) or otherwise defined as Core Areas. In particular, relascopic areas and transects were carried out to detect regeneration on the following plots: 134-133-135-136-11-97-95-96-18-19-20-7. The core areas are characterised by a multi-layered structure, with a wide variability in age and size of the holm oak specimens (Figure 6a and 6b).
In addition, part of the survey focused on monitoring the status of transition forest areas referred to as Biodiversity Islands. In the latter, the structure is predominantly monoplane, with a reduced number of successional stages reflected in the reduced number of size classes (Figure 6c).

Figure 6. From left to right: Figures a and b - parts of core areas show multi-layered structures with signs of senescence, such as laying and standing deadwood and large trees. Figure c, right shows a typical stretch of Biodiversity area, monoplane with reduced variability in age and size.

The objective is the application of the allometric approach to estimate the degree of disturbance by means of structural surveys in the two forest types described above located in the 'Sardinia (IT) Site ITB022212 - Supramonte di Oliena, Orgosolo e Urzulei - Su Sercone'.

A total of 50 relascope areas were carried out in the core areas and 20 in the Biodiversity islands. Regeneration transects were surveyed for each of these. However, many of these were classified as irrelevant because the regeneration, not only of holm oak but also of other species, was completely absent. Only 20 transects were able to count an actual presence of tree and/or shrub regeneration. In total, the survey took 8 working days with two teams of 3-4 people depending on the availability of personnel.

Allometric *scaling* at individual level.

Scaling of crown volumes and heights were measured for a total number of 111 trees throughout the portion of the forest classified as holm oak forest. The height classes measured cover a range of size classes from 0 to 27 metres.
Figure 7 shows the variation of volume with height, while Table 3 summarises the statistical parameters of the relationship using the linear model analysis described lm(log(V_{cro}) ~ log(h). From this relationship, it can be seen that the exponent *a(1+2H)* = 3.00.
The variation of height with crown radius is then determined (Figure 8) in order to extrapolate the parameters necessary for applying the H-model to the stand for subsequent comparison with the actual state at the present time. Table 4 summarises the statistical parameters of this relationship, from which it can be seen that the exponent *b* of the relationship $h \propto r^b$ is equal to 0.7. We therefore obtain that the probability of the distribution of the diameters is defined by:

$$P(r) = P(h)\frac{dh}{dr} \propto r^{-ba(1+2H)+b-1} \propto r^{-0.7*0.3+0.7-1=-2.4}$$

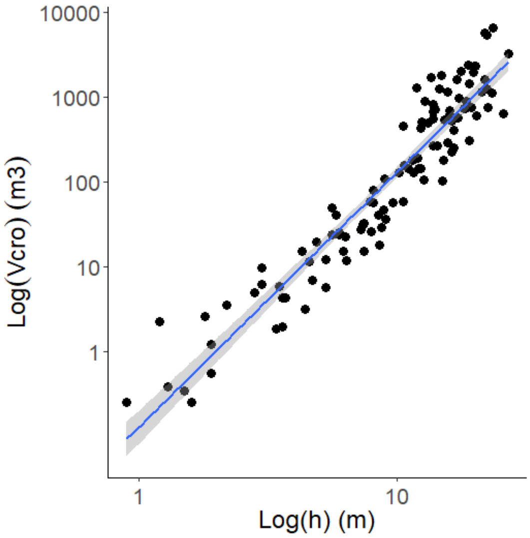


Figure 7. *Scaling* of crown volume as a function of height.

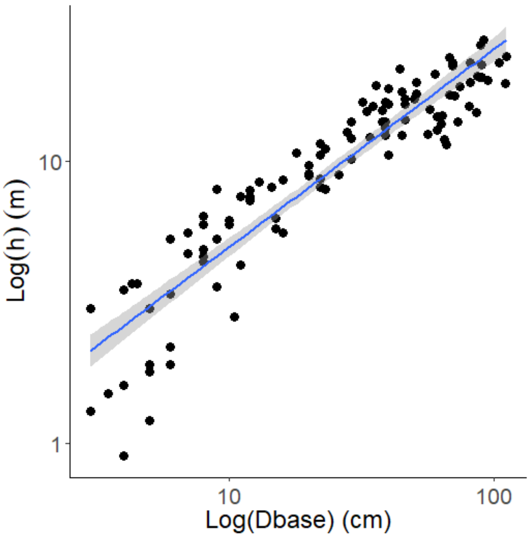


Figure 8. *Scaling* of height as a function of diameter.

Table 3. Detail of linear regression *lm(log(V) ~ log(h),* with R^2, standard error and upper & lower confidence limits of parameters V and h.

Linear model	intercept	exponent	R2 mrsq	sqrt
lm(log(Vcro) ~ log(h)	-2.042	3.003	0.8977	0.7843992
s.e.	0.22822	0.09754		
LL CI 95%	-2.494369	2.809804		
UL CI 95%	-1.589644	3.196477		

Table 4. Detail of linear regression *lm(log(h) ~ log(D*), with R^2, standard error and upper & lower confidence limits of parameters V and h.

Linear model	intercept	exponent	R2 mrsq	sqrt
lm(log(h) ~ log(D)	-0.01614	0.70375	0.852	0.2976606
s.e.	0.09367	0.02822		
LL CI 95%	-0.2018145	0.6478156		
UL CI 95%	0.1695425	0.7596863		

Actual distribution of stand diameter classes in the *core areas*

Considerable diameters of up to 220 cm have been measured in the *core areas* and, in all probability, individuals with even larger diameters exist within the entire forest. However, these large sizes are only present with a minimal frequency, counting for example 0.005 trees/ha for the 220 cm class. The 1 cm classes allowed us to include in the frequency distribution also all the very small-sized regeneration detected with the transects. In particular, the seedlings falling in the 1 cm class amount to 12 229 trees/ha. And although the number of individuals in this 1 cm class is extremely high, in the following diameter classes a dramatic drop in the number of individuals can be seen, which immediately drops to 12 trees/ha for the 3 class, and to 7 trees/ha for the 4 class.

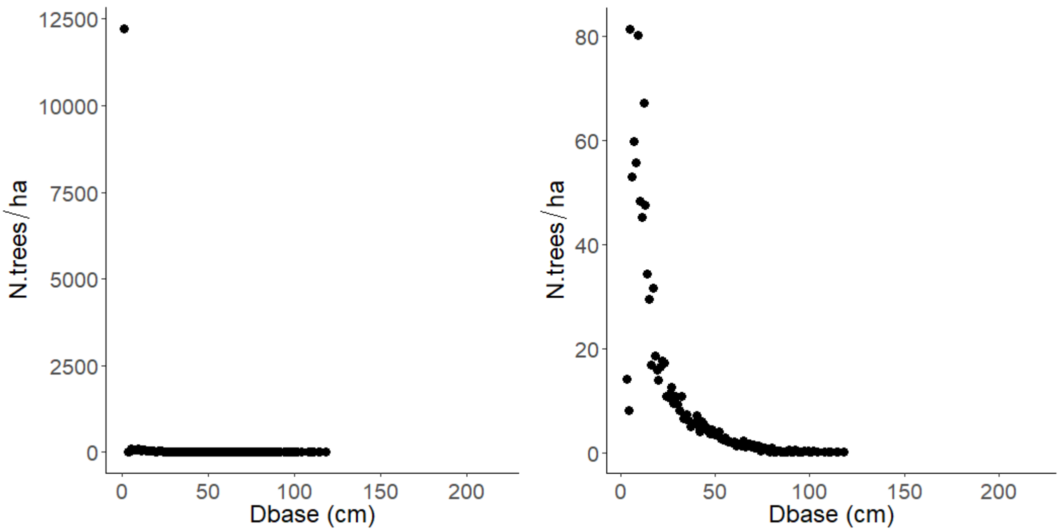


Figure 9. Frequency of the number of trees per hectare by diameter classes. Left: including regeneration with individuals of diameter < 1 cm; right: excluding regeneration (only trees with diameter at base > 1 cm).

By comparing the number of trees per hectare measured per diametric class of the actual state and the prediction of the H-model (Figure 10), two different trends can be observed. I) taking it as a reference that the number of seedlings in the 1 cm class is close to potential, the subsequent diametric classes in the actual state have significantly fewer than the number predicted by the model curve. In other words, small cohorts are scarcely present in this forest system. It follows that the energy not utilised by them must be redistributed to other diametric classes. In this sense, we can therefore see that II) large cohorts are present outnumbered by the prediction. We therefore have a population imbalance where the large and old trees use up resources that would be allocated to the smaller and younger cohorts that fail to establish themselves and transition into the adult stages.

As we note from Figure 10 and as defined in principle by the H model, the distribution of tree sizes is not a pure power law, but is finite (finite size-scaling), i.e. it has a limit to the maximum height. The curvature *cutoff* represents the maximum height *hc*. In this case we can see that the curvature in the largest diameters in the distribution of the actual relief, corresponds to the diameter 73 cm for which we obtain the maximum representativeness of the power function interpolation. This value corresponds to a height of 20 m, which is the maximum height that is sustainable for this stand.

We then derive a simplified graph where the comparison between the power curves is better (Figure 11). Here again, we note that the current state presents a supernumerary of large trees and a persistent shortage of young trees.

We hypothesise that a shortage of individuals in the small diameter classes (<10 cm) is due to the intense grazing pressure that tends to remove both the seed (acorns) preventing their germination mainly by wild pigs, and the young trees by depriving them of their photosynthetic apparatus (by sheep and goats). However, the removal of very young seedlings that have just germinated (1 year old) seems to be more worrying than the removal of trees with diameters between 1 and 10 cm, the disappearance of which seems to be attributable to sheep/goat/cattle grazing.

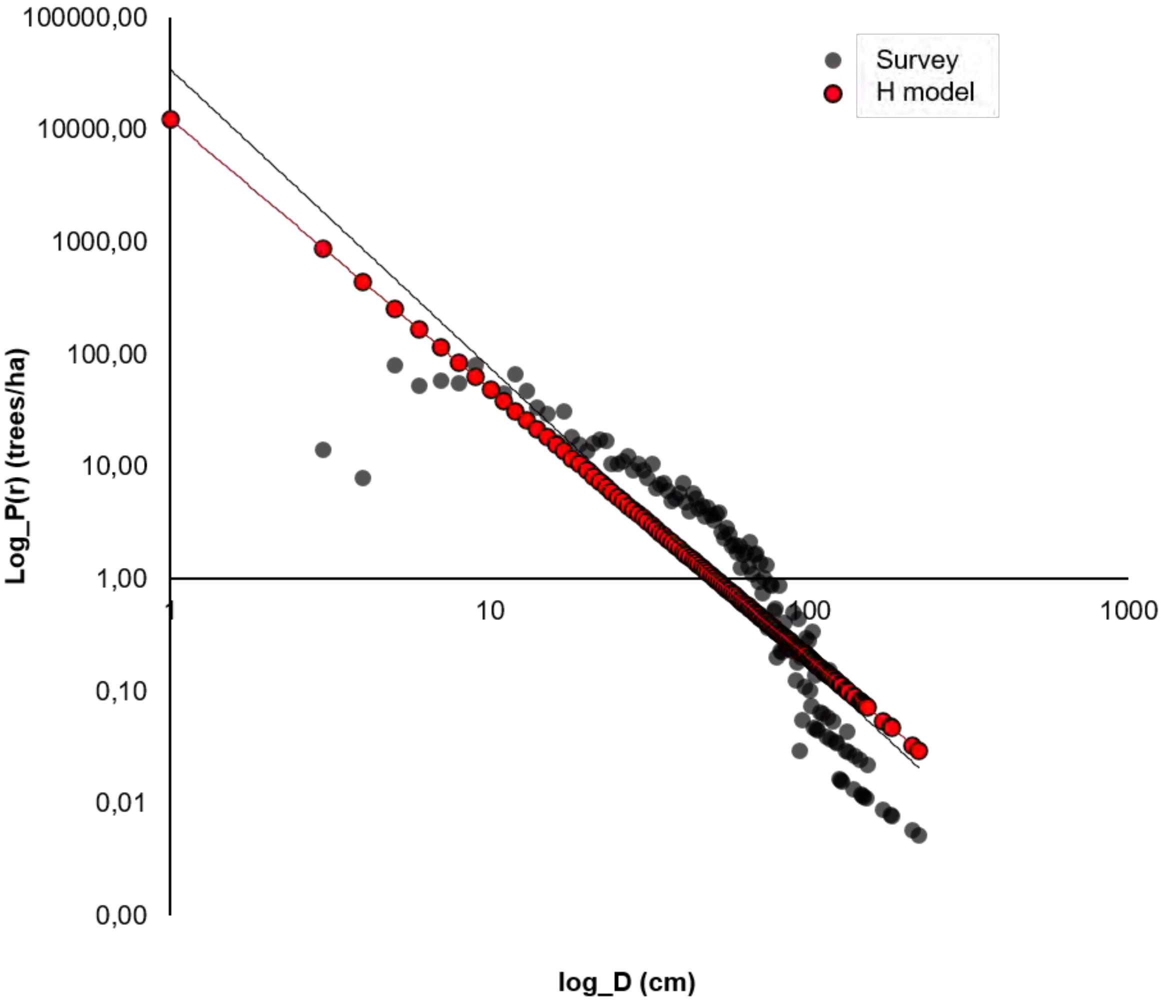


Figure 10. Frequency of the number of trees per hectare by diametric classes in the actual state ($y=34381x^{-2.6}$) and in the potential state as estimated by the H-model ($y= 12389x^{-2.4}$) in *core areas.* Visualisation on a logarithmic scale.

From the H model curve, we can realise how far the actual state is from the maximum potential of the Montes forest structure in the *core areas*. Through the comparison between the actual state and the potential state estimated with the H model, we can also estimate what the ideal number of trees per diametric class could be in order to lead the stand to its maximum potential use of the resource (Figure 12) taking into account that the starting point is the current number of seedlings per hectare.

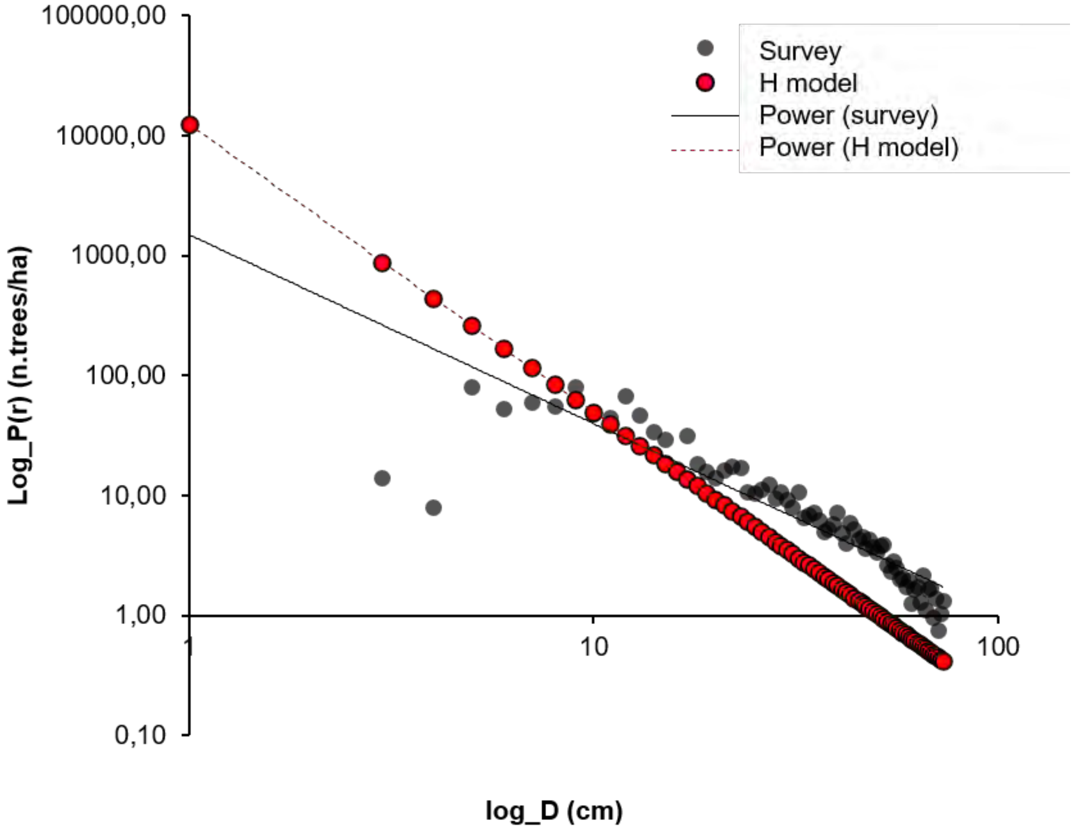


Figura 11. Frequency of the number of trees per hectare by diametric classes in the actual state ($y=1489.4x^{-1.57}$) and in the potential state as estimated by the H-model ($y= 12389x^{-2.4}$) in *core areas.*

Figure 13 and Table 5 show an example where the missing trees are determined by the difference between the current distribution and that predicted by the model from the positive figures, while the negative figures indicate the possible removal of the indicated number of individuals in order to free up energy for the younger cohorts. As we can see, however, this approach would imply a substantial removal of individuals especially in the larger diametric classes.

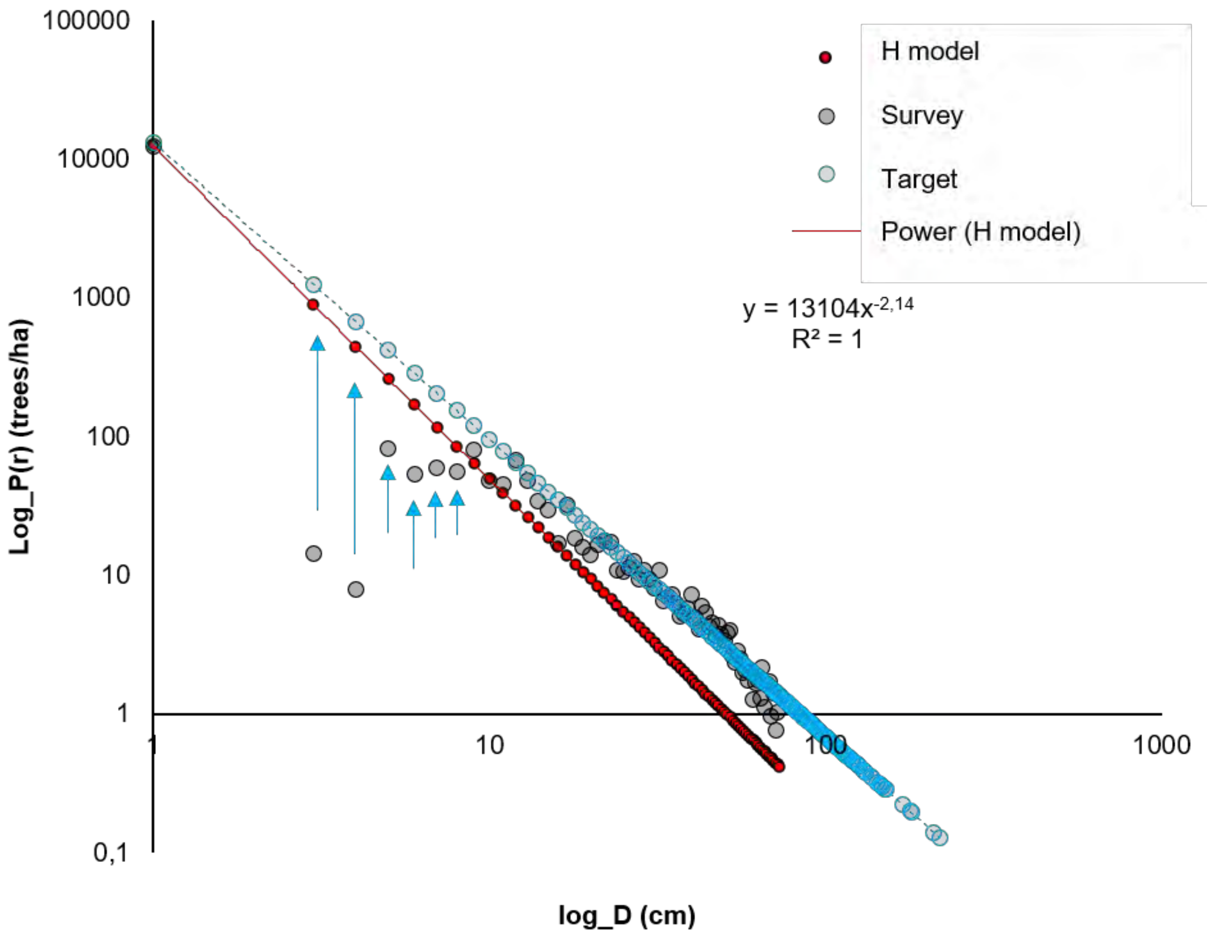


Figure 12. Frequency of the number of trees/ha by diametric classes in the actual state ($y=1489.4x^{-1.57}$), n the potential state as estimated by the H-model ($y= 12389x^{-2.4}$) within *core areas,* and in the hypothetical target state to which the stand should be led ($y=13104x^{-2.14}$). The blue arrows indicate the sub-numerary classes.

Table 5. Extract from the descriptive table of missing trees by diametric class in the *core areas* (cl. up to 20cm). Estimate made by difference between the number of trees/ha estimated with the H-model and the survey in June 2023 in Montes Forest.

Diameter (cm)	Real State	H-model n. trees/ha	Missing trees	Diametro (cm)	Real State	H-model n. trees/ha	Missing trees
1	12229	12389	160	11	45	39	-6
3	14	887	873	12	67	32	-35
4	8	445	437	13	47	26	-21
5	82	260	179	14	34	22	-12
6	53	168	115	15	29	19	-11
7	60	116	56	16	17	16	-1
8	56	84	29	17	32	14	-18
9	80	64	-17	18	18	12	-6
10	48	49	1	19	16	11	-5

Since it is not easy to bring the stand back close to the prediction line of the H model in the short term, the definition of a target curve is proposed here (Figure 12, in light blue), which implies moderate intervention aimed as far as possible at maintaining the large trees present in their current state, which are of great value not only naturalistically but also culturally. The number of individuals to be secured per class has also been calculated for this 'target' curve (Figure 13b). It will therefore be necessary to determine strategies to encourage consistent regeneration by mediating the survival of seedlings and their transition to the 15-20 size classes with the management of silvopastoral areas.

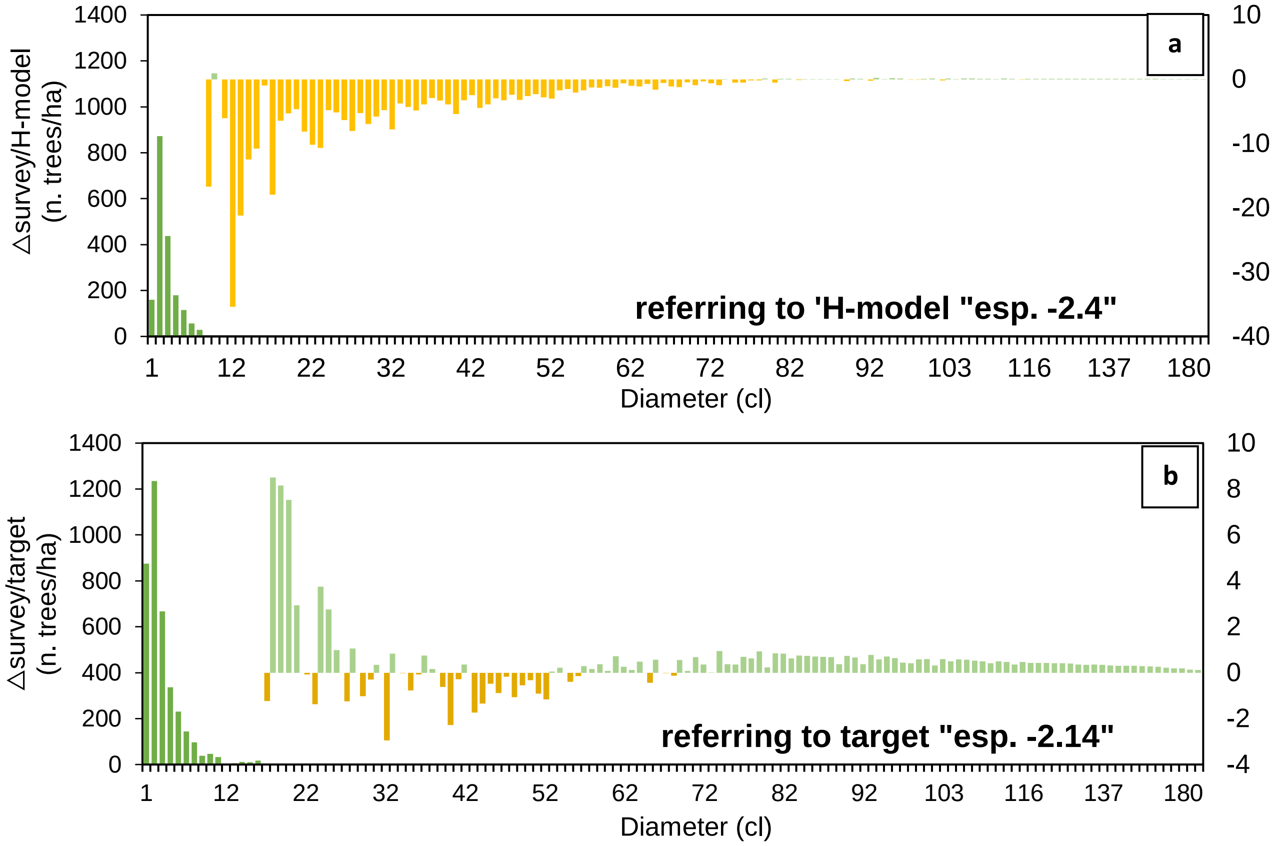


Figure 13. Number of missing (green, primary axis) and surplus (yellow, secondary axis) trees per hectare as differential values for comparison between the actual survey and the H model (exponent -2.4) in figure **a** and the actual survey and the target curve (exponent -2.14) figure **b**.

Actual distribution of stand diameter classes in the *biodiversity islands*

In the biodiversity islands, the maximum diameter found for *Q.ilex* was 75 cm (Figure 14). In these areas, there was as little regeneration as in the *core areas*, but in addition to this, trees in the 1 cm class or smaller were absent. We found an abundance of individuals for class 8 (120 trees/ha).

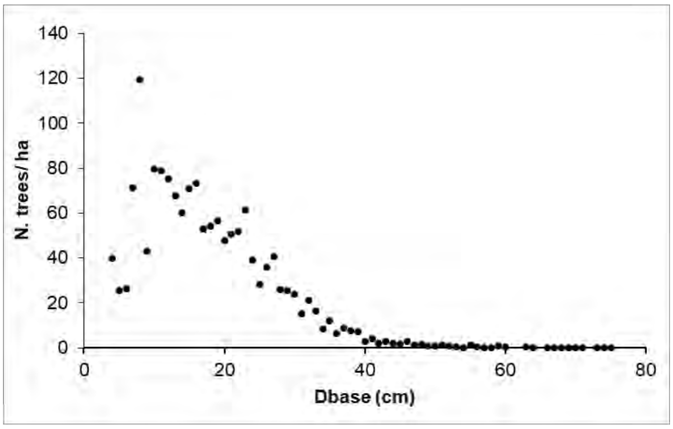


Figure 14. Frequency of the number of trees/hectare by diametric classes in the *biodiversity islands*.

A comparison of the actual state in the biodiversity islands with their maximum potential (Figure 15) reveals a clearly more unbalanced situation than in the core areas. Again, most individuals are missing in the small diametrical classes, but here the frequency per diametrical class is still almost constant (a symptom of previous management) and large trees are missing.

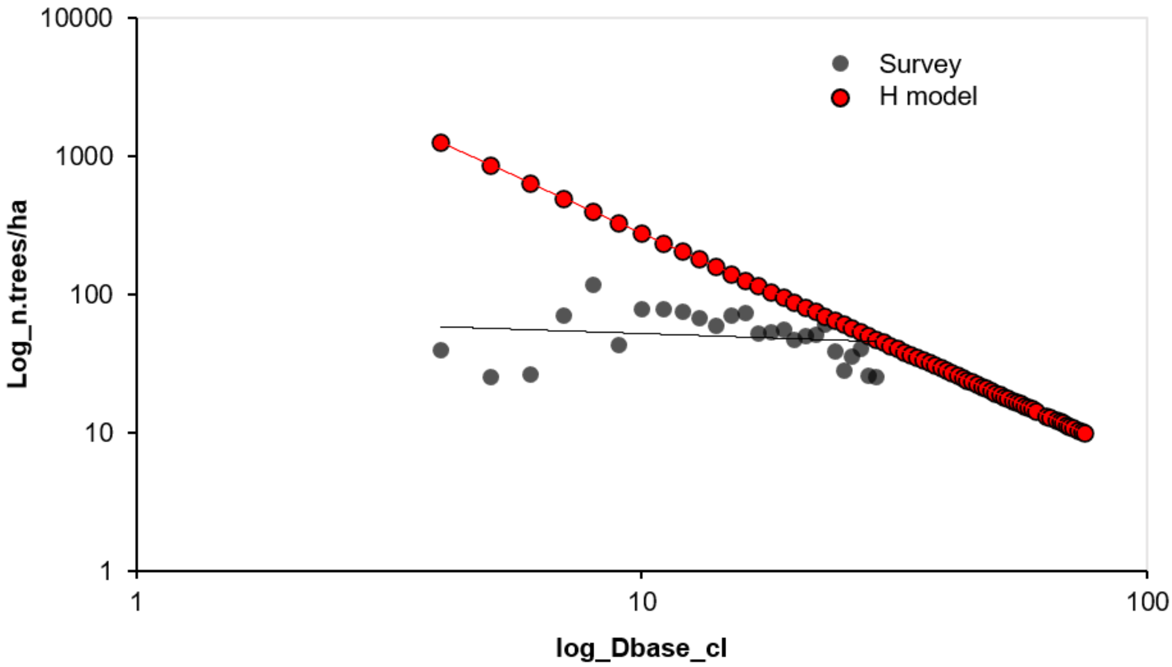


Figure 15. Frequency of the number of trees/hectare by diametric classes in the actual state ($y=78.348x^{-0.178}$) and in the potential state as estimated by the H-model ($y= 12389x^{-2.4}$) in *biodiversity islands.*

Here again, Table 6 shows a forecast of the number of trees per hectare to be ensured in order to achieve a structure oriented towards expressing the maximum potential of the holm oak forest. It should be noted that in this case no negative numbers are reported and therefore there are no trees to be removed in the higher classes. At the same time, it will have to be evaluated in the management planning phase whether it is appropriate to open forest gaps to encourage localised regeneration.

Table 6. Descriptive table of missing plants by diametric class in the *biodiversity islands*. Estimate made by difference between the number of trees per hectare estimated with the H-model and the survey in June 2023 in Montes Forest.

Diam (cm)	Survey	H-model	Missing trees	Diam (cm)	Survey	H-model	Missing trees
	n.trees/ha				n.trees/ha		
1			12389	33	16	39	22
4	40	1258	1218	34	8	37	29
5	25	870	845	35	12	35	23
6	27	644	618	36	6	34	27
7	71	500	428	37	9	32	23
8	119	401	281	38	7	31	23
9	43	330	287	39	7	29	22
10	80	277	198	40	3	28	25
11	79	237	158	41	4	27	23
12	75	205	130	42	2	26	24
13	68	180	112	43	3	25	22
14	60	159	99	44	2	24	22
15	71	142	71	45	2	23	21
16	73	128	54	46	3	22	20
17	53	116	63	47	1	22	20
18	54	105	51	48	2	21	19
19	56	96	40	49	1	20	19
20	48	88	41	50	1	19	19
21	51	82	31	51	1	19	18
22	52	76	24	52	1	18	18
23	61	70	9	53	0	18	17
24	39	65	26	54	0	17	17
25	29	61	33	55	1	17	15
26	36	57	22	56	1	16	16
27	41	54	13	57	0	16	16
28	26	51	25	58	0	15	15
29	26	48	22	59	1	15	14
30	24	45	21	60	1	14	14
31	15	43	28	63	0	13	13
32	21	41	20	64	0	13	13

Data collection fieldsheets

There are four data collection fieldsheets. It is at the discretion of the surveyors' team whether to transfer them to a spreadsheet or carry out the survey in paper form.

- Sheet A: numerical series for random placement of survey areas
- Sheet B: crown volume survey
- Sheet C1: relascopic areas survey
- Sheet C2: survey of regeneration transects

A combined C1+C2 sheet is also included, to be used at the discretion of the surveyors' team, which could be used to optimise surveys in the event of forest cases where regeneration is reduced to only very small individuals and shrubs.

SHEET A: numerical series for random placement of survey areas

Example of numerical series for the randomised placement of survey areas. The series can be generated with the functions = RANDBETWEEN (1,120) e = RANDBETWEEN (0,359).

distances (steps) 1-120		
49	95	108
1	54	34
41	93	95
84	37	120
93	56	113
91	26	25
89	120	120
3	38	14
50	22	66
90	44	24
7	114	94
9	93	3
15	111	116
4	89	69
35	14	56
74	52	24
47	78	11
53	1	75
63	5	21
2	104	6
52	38	63
33	56	116
40	17	109
62	47	60
42	81	70
71	99	10
35	20	7
31	87	89
72	98	85
76	91	101
56	3	3
16	98	112
61	2	119
69	94	77
75	62	40
30	44	13
27	50	81
55	86	10
64	84	24
74	120	27
4	79	97
22	53	22
32	108	37
16	14	78

Direction (° in relation to the N) 0-359		
199	153	355
228	281	48
228	19	273
204	289	62
16	130	148
48	12	267
168	160	4
37	167	279
1	96	350
344	172	277
353	349	69
223	292	26
200	289	249
325	129	315
150	11	356
211	136	280
18	178	79
143	187	81
74	4	198
125	253	273
48	329	162
72	210	337
338	155	19
22	27	172
171	257	72
353	60	311
162	258	47
85	309	187
128	108	121
188	323	120
172	171	43
8	197	264
167	37	347
271	230	94
329	31	263
206	53	57
305	300	74
319	114	34
176	238	23
189	208	301
24	316	279
72	170	129
237	115	142
10	202	256

SHEET B: crown volume survey

SHEET B – CROWN VOLUME								SHEET N ___ OUT OF_____			
DATE	LOCATION:										
								Crown radii on living branches (m)			
Range h	**Species**	**h_{tot} (m)**	**Circ. BH (cm)**	**Circ. base (cm)**	**DBH (cm)**	**D base (cm)**	**h 1° living branch (m)**	**R1** longer at the base) **(m)**	**R2** (180° from R1) **(m)**	**R1 @½l_{cro} (m)**	**R2 @½l_{cro}** (180° da R1 @½lcro) **(m)**
0-2 m											
2-4 m											
4-6 m											
6-8 m											
8-10 m											

PAGE 1 OF 3

SHEET B – CROWN VOLUME								SHEET N ___ OUT OF_____			
DATE	LOCATION:										
								Crown radii on living branches (m)			
Range h	Species	h_{tot} (m)	Circ. BH (cm)	Circ. base (cm)	DBH (cm)	D base (cm)	h 1° living branch (m)	R1 longer at the base) (m)	R2 (180° from R1) (m)	R1 @½l_{cro} (m)	R2 @½l_{cro} (180° da R1 @½lcro) (m)
10-12 m											
12-14 m											
14-16 m											
16-18 m											
18-20 m											

PAGE 2 OF 3

SHEET B – CROWN VOLUME								SHEET N ___ OUT OF_____			
DATE		LOCATION:									
Range h	Species	h_{tot} (m)	Circ. BH (cm)	Circ. base (cm)	DBH (cm)	D base (cm)	h 1° living branch (m)	R1 longer at the base) (m)	R2 (180° from R1) (m)	R1 @½l_{cro} (m)	R2 @½l_{cro} (180° da R1 @½lcro) (m)
20-22 m											
22-24 m											
24-26 m											
26-28 m											
28-30 m											

PAGE 3 OF 3

SHEET C1: Relascopic areas survey

Survey sheet C1 - Relascopic areas (strip n. 1)		sheet: _ of _
n. area	site name	GPS coordinates
	pacel	N
date	forest map	E

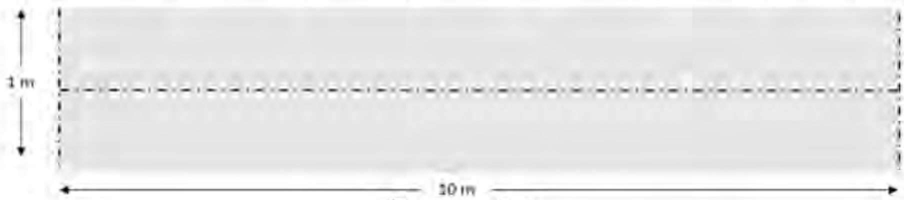
n. tree	species	1/0.5	Circ.Base (cm)	D.Base (cm)	n.tree	species	1/0.5	Circ.Base (cm)	D.Base (cm)
1					41				
2					42				
3					43				
4					44				
5					45				
6					46				
7					47				
8					48				
9					49				
10					50				
11					51				
12					52				
13					53				
14					54				
15					55				
16					56				
17					57				
18					58				
19					59				
20					60				
21					61				
22					62				
23					63				
24					64				
25					65				
26					66				
27					67				
28					68				
29					69				
30					70				
31					71				
32					72				
33					73				
34					74				
35					75				
36					76				
37					77				
38					78				
39					79				
40					80				

SHEET C2: survey of regeneration transects

SHEET C2

Trees with h < 200 cm
Transect: lenght = 10 m, 1 m wide

Regeneration D > 1 cm							
N. Area	**R:**		**Location**				**GPS coordinates**
N° of the related relascopic area			**Stand**				N
Date			**Map**				E
N. tree	**Species**	**D.Base (cm)**		**N. tree**	**Species**	**D.Base (cm)**	
1				21			
2				22			
3				23			
4				24			
5				25			
6				26			
7				27			
8				28			
9				29			
10				30			
11				31			
12				32			
13				33			
14				34			
15				35			
16				36			
17				37			
18				38			
19				39			
20				40			



Regeneration

Small individuals, D<= 1 cm		**Cushion-shaped shrubs**					
Species	**Tot. N. trees D < 1 cm**	**Species**	**% crown within the transect**	**D.base (cm)**	**h (cm)**	**r_1 (cm)**	**r_2 (cm)**

SHEET C1+C2: combined

SHEET C1+C2 combined

Relascopic areas
Transect with only regeneration <=1 cm: Dbase and shrubs

Relascopic areas (Band 1)		
n. area	**Location**	**GPS coordinates**
	Stand	**N**
Date	**Map**	**E**

N. tree	Species	1 / 0.5	Circ.Base (cm)	D.Base (cm)	N. tree	Species	1 / 0.5	Circ.Base (cm)	D.Base (cm)
1					41				
2					42				
3					43				
4					44				
5					45				
6					46				
7					47				
8					48				
9					49				
10					50				
11					51				
12					52				
13					53				
14					54				
15					55				
16					56				
17					57				
18					58				
19					59				
20					60				
21					61				
22					62				
23					63				
24					64				
25					65				
26					66				
27					67				
28					68				
29					69				
30					70				

Regeneration trees with h < 200 cm – transect lenght = 10m, 1 m wide

Small individuals, D<= 1 cm		D > 1 cm or cushion-shaped shrubs					
Species	N. trees D < 1 cm	Species	D.base (cm)	h (cm)	S/P	r_1/l_1	r_2/l_2