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# USING THE HART-BECKING *SPACING INDEX* IN A STUDY OF THE NATURALISATION OF *PINUS HALEPENSIS* MILLER PLANTATION STANDS IN THE SOUTH-EASTERN SALENTO PENINSULA

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***Abstract***

*This study aimed to define a method for surveying the naturalisation processes occurring in adult plantations stands of Aleppo Pine.*

*In stands planted in the south-eastern Salento peninsula (southern Italy) during the 1950s, 23 study plots were identified, each with a different level of naturalisation.*

*A survey was performed in these plots on the demographic and biometrical parameters commonly used in silvicultural studies, not only for the tree populations but also for the shrubs.*

*The results indicate that, of all the parameters considered, it is the Hart-Becking Spacing Index which seems to best represent the processes being surveyed.*

*It can therefore also be used to determine the appropriate intensity of thinning in order to encourage the development of such naturalisation processes.*

## INTRODUCTION

Many forestations carried out in Italy early in the second half of the last century using conifers from the *Pinus* genus are undergoing naturalisation, being enriched by the spontaneous spread of native species which make up the forest, forest-maquis, and maquis of the surrounding areas.

The observations of AA. in Mediterranean pine stands planted at the same time in Apulia have shown that this process is affected by the amount of light reaching the ground.

Indeed, the spontaneous spread of understorey species in these pine plantation stands is absent - or at most incipient - both in the most densely wooded areas, and in the more open pine plantation stands, which are colonised by other species from the mantle community.


Fig. 1. Location of the stands

It thus became clear that there is a problem of defining the intensity of the thinning that needs to be carried out, in order to improve the structure of the pine forest and, at the same time, to encourage (or at least not impede) the establishment and development of plant communities from the understorey, which over time may become forest and forest-maquis, in a balanced environment.

This study therefore sets out to make a methodological contribution that will serve to define the intensity of thinning required, and to provide effective achievable results and potential applications.

The study was carried out on stands of Aleppo Pine (*Pinus halepensis* Miller), with Cypress (*Cupressus sempervirens* L.), planted in an area of around 150 ha after World War Two in the irrigation districts around the Alimini Lakes, during reclamation works in the south-eastern part of the Salento peninsula, which began in the 1930s.

These stands have in the past undergone clearing and thinning, the latter being carried out under a specific forest management plan.

Following these actions, a differentiated understorey became established in terms of composition and development, with changes to the final density of the tree storey.

The understorey is made up mainly of Kermes Oak (*Quercus coccifera* L.), Phyillyrea (*Phillyrea latifolia* L.), Mediterranean Buckthorn (*Rhamnus alaternus* L.), Myrtle (*Myrtus communis* L.), Wild Olive (*Olea europaea* L., var. *sylvestris* Brot.), Lentisk (*Pistacia lentiscus* L.), Butcher's Broom (*Ruscus aculeatus* L.), Mediterranean Honeysuckle (*Lonicera implexa* Aiton) and Italian Sarsaparilla (*Smilax aspera* L.).

Within the pine forests examined in this study, in sample populations characterised by different stages of naturalisation, the authors looked for any correlations between the stages of naturalisation and the values for several biometric parameters of the tree storey.

The stages of naturalisation were determined with the Magini *Regeneration Index* (1967), for shrub species of the developing understoreys.

The biometric parameters were chosen from among the most widely used ones for determining the density of a storey and the intensity of silvicultural management required.

In concrete terms, this means the number of trees, the basal area and the crown cover per hectare.

Moreover, for each sample population, the Hart-Becking *Spacing Index* value was calculated, which as is known correlates the mean distance between trees and the dominant height, expressions of the stand density and fertility levels, respectively.

This Hart-Becking *Spacing Index* has been widely used both in Italy and abroad (Bouchon, 1966; Ciancio & Martire, 1971; Ciancio & Nocentini, 1978) to determine the intensity of the thinning regime required in the broadleaf and coniferous stands planted for timber production purposes.

In this study, we aimed to verify the reliability of this *Index* in representing, even summarily, the characteristics of tree populations at different stages of naturalisation.

## METHODOLOGY

The study was carried out in various phases, and the methodology adopted is set out below.

The first phase aimed to outline the physical, biophysical and biological environment of the area chosen for the creation of these stands.

Naturalisation class 1

The second phase aimed to define, within the same stands, a suitable number of classes to represent the ongoing naturalisation, and an adequate number of study plots, where demographic and biometric investigations were carried out, not only into the tree populations, but also into the shrub and herbaceous layers.

And finally, the third phase aimed to determine the correlations between these various parameters.

Naturalisation class 2

In order to outline the physical environment, we described the most important geomorphological and hydrogeological characteristics, based on the results of the latest scientific contributions and integrated by numerous observations carried out in the field. Particular attention was paid to factors which directly affect vegetation, such as the morphology of the terrain, outcrops of rock, surface phreatic water and the physical and chemical processes involved in soil formation.

The study was completed by performing a survey of the climate and bioclimate, using methods proposed by Emberger (1930-71) and by Montero De Burgos & Gonzalez Rebollar (1982). The study was performed by processing data from the nearest ombrothermic weather station of the regional hydrological service, i.e. Otranto, about 7 km from the study area. The reference period covered the fifty years from 1951-2000.

The biophysical environment was outlined by considering the findings of the main studies performed in the study area and in neighbouring areas, together with a series of first-hand observations.

We analysed the biological environment with a customised census of the various entities making up the residual vegetation, i.e. forest, forest-maquis, maquis and garrigue.

The pine forests in the study were divided into five classes, each characterised by a different level of naturalisation, within which 23 study plots were identified, as shown in the table below:

| Naturalisation class n. | Understorey features | Understorey height | Study plots n. |
|---|---|---|---|
| 1 | absent or incipient | - | 3 |
| 2 | aggregated in small groups | < 0,50 m | 6 |
| 3 | widespread but not dense | < 0,75 m | 4 |
| 4 | widespread and dense | < 1,00 m | 6 |
| 5 | widespread and very dense | > 1,00 m | 4 |
| Total | | 23 | |

The study plots were located as deep as possible within the reference zones for each naturalisation class, thus avoiding places subject to anomalous insolation, due to gaps in the tree canopy (whether these were clearings in the forest or due to road developments).

They are circular with a diameter of 30 m.

Within each one, we performed a demographic analysis of the tree species. For each tree, the following measurements were made:
- two right-angle trunk diameters, 1.3 m above ground level, with tree callipers;
- tree height, with a Blume-Leiss hypsometer;
- eight crown radii, using a tape measure and stakes.

These data were processed to get the per-hectare values for total tree numbers, for basal area and for crown cover in each study plot.

Naturalisation class 3

The next task was to determine the Hart-Becking *Spacing Index* for each study plot, measured as a percentage ratio between:
- the mean distance between the trees, defined as a function of the number of trees per hectare;
- the dominant height, calculated as the mean arithmetic height of the 100 largest-diameter trees per hectare (CIAncio e Nocentini, 1978), in relation to the area of the study plots.

Naturalisation class 4

Finally, for each class of naturalisation, mean values were calculated for the parameters under consideration.

One north-south transect 1.5 metres wide was identified within each study plot, roughly parallel with the coast.

Each transect was subdivided into 1.5 metre segments, numbered sequentially from 1 to 20.

In three of these subsegments, chosen at random, components of the arborescent, shrub and herbaceous layers were censused for species, using a tape measure to determine their height, expressed in metres.

Processing these data, for the shrub layer alone, produced values for the Magini *Regeneration Index*, equal to the product of the mean height of the plants found, multiplied by the number of plants per $m^2$. This *Regeneration Index* was chosen because it is easy to calculate and interpret. It has proven to be effective in a number of surveys, some of which have been in Mediterranean environments.

Naturalisation class 5

## RESULTS

### Geological, hydrogeological and morphological characteristics

Along the coast from Roca Vecchia to Otranto, which includes the study area, there are several outcrops (Rossi, 1969) of Pliocene marine sediment; they are formed of clayey calcarenites, more or less compact, stratified into layers, each of which is under 1 m thick and highly permeable.

This lithostratigraphic unit from the *Salento Calcarenites* group is fossil-rich and 40-50 m thick.

At the base of these units are gravel and conglomerates, included in a calcarenite matrix that is fairly or totally impermeable.

Both units lie on a calcareous substrate formed during the Mesozoic.

On a morphological step, corresponding to an ancient coastline, the two units come into contact with *Calcareous sands*, which are often interspersed with marly calcarenites and chalky organogenic debris, that are fossiliferous and indistinctly layered.

The water circulates in these units to form (Maggiore & Pagliarulo, 2002) a discontinuous groundwater system, with the result that there are two distinct phreatic levels.

The first, on the surface, is fed by precipitation followed by interflow which finds a number of infiltration points in the calcarenite outcrops, which as already mentioned are permeable. Some small sinkholes are a further invitation to form preferential infiltration pathways.

The waters in this surface table which also feeds the Alimini Lakes are low in salinity (less than 0.5 g/l), making them suitable for drinking water.

The second water table, around 200 m below the surface, is located in the Mesozoic calcareous rock, and is made up of brackish water, lying on the water of the Adriatic Sea, which is a continental invasion.

The terrain in the study area is characterised by the presence of two small reliefs, between which the Alimini Lakes formed.

They run north-south, parallel to the coastline, about 2 km apart: the one closer to the sea reaches a height of 19 m asl, whereas the one further inland is at most 35 m high.

The slopes running down to the lakes are very steep and cover a small area, whereas the slopes on the other side are much gentler and therefore much longer.

Close to the sea, there are recent sand dunes which give a dynamic appearance to the physical landscape of the coast.

## Climatological and bioclimatological characteristics

The results of processing climate data from the ombrothermic weather station at Otranto are summarised in the table below:

| **- Mean air temperature (°C):** | |
|---|---|
| .year | 16.6 |
| .autumn | 18.2 |
| . winter | 10.4 |
| . spring | 14.4 |
| . summer | 23.5 |
| . max in hottest month (August) | 28.9 |
| . max in coldest month (January) | 6.4 |
| . annual range | 22.5 |
| . number of days with frost (Tmin 0°C) | 1.1 |
| . number of summer days (25°Tmax 30°) | 80.5 |
| . number of tropical days (Tmax 30°) | 23.4 |

| **- Total precipitation (mm)** | | | |
|---|---|---|---|
| . year | 790.8 | | |
| . autumn | 321.7, | with daily intensity of | 15.7 |
| . winter | 260.6, | " " " " | 10.0 |
| . spring | 147.2, | " " " " | 8.6 |
| . summer | 61.3 | " " " " | 9.6 |

The rainfall regime is *sub-equinoctial*, on the Adriatic side, due to the relative maximum (72.23 mm) occurring in March.

According to Köppen's classification (Pinna, 1977), the climate in Otranto is *Csa*, i.e. *humid mesothermic* (*C*), with the least rainfall occurring in summer (*s*) and the mean temperature of the hottest month being over 22°C ( *a*).

The bioclimate analysis was performed using the methods proposed by Emberger for mediterranean climate regions, and which require a preliminary assessment of summer drought.

This assessment was performed, as suggested by Emberger, using GIacobbe's *Summer hydrological index* (1938) (*I.i.e. = Pe/M*), which had a value of 2.1, showing that the summers are dry, and therefore that the climate is *mediterranean* (Daget, 1980).

This enabled us to calculate the Emberger *Pluviothermic quotient* (1971) [$Q_2 = 2000P/(M^2-m^2)$], which was 121.

Figure 2 shows the ombrothermic diagram, created with the methods suggested by Emberger, and modified by Akman & Daget (1971), comparing the values of $Q_2$ and $m$.

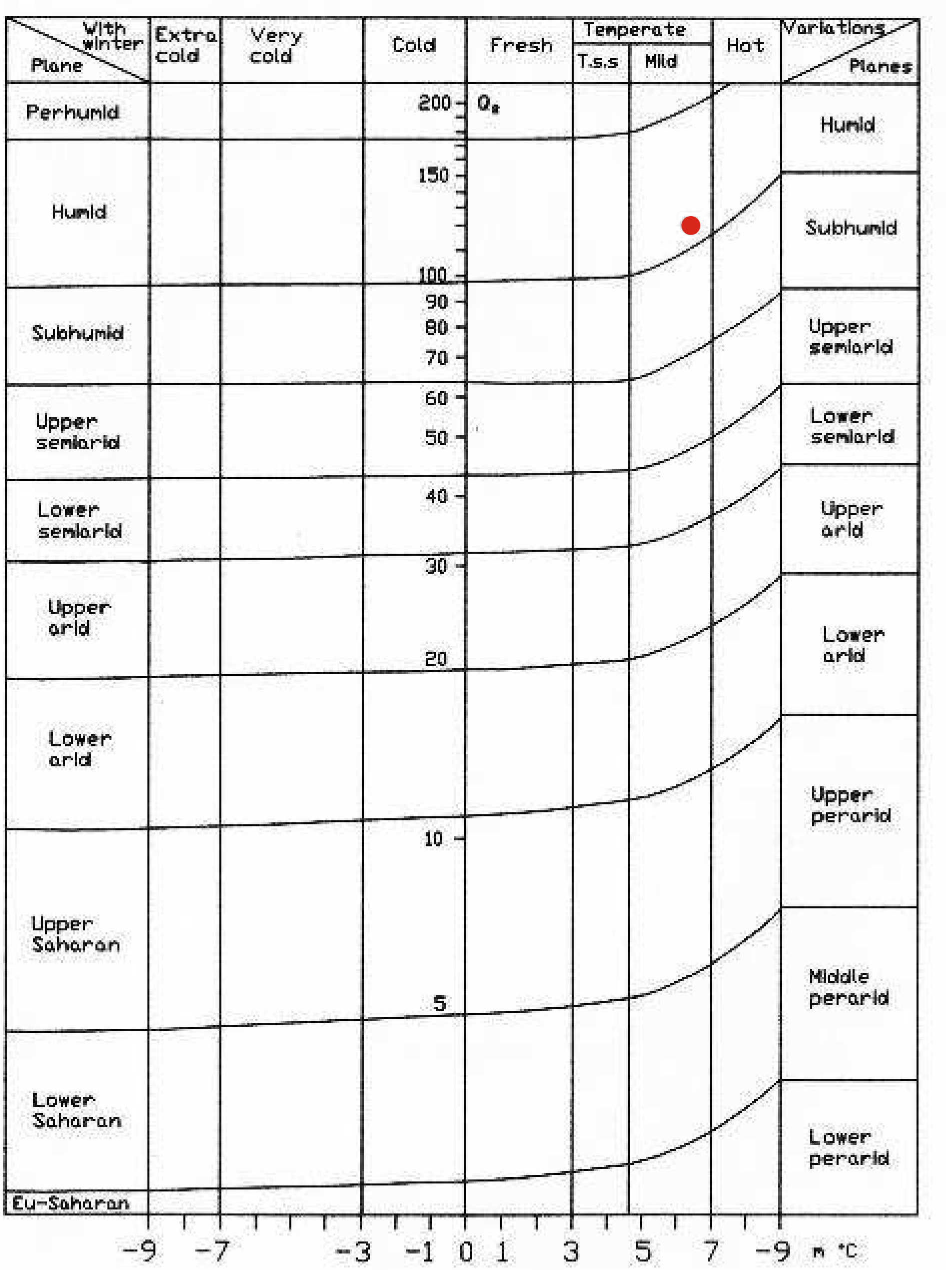


Fig. 2. Ombrothermic diagram, drawn up using the methods proposed by Emberger and modified by Akman & Daget, for the Otranto weather station ().

It follows that Otranto, and probably the surrounding areas, including the study area, come under the *humid* bioclimate belt, with *mild temperate* winters.

The bioclimatic diagram was then drawn up using the methods proposed by Montero de Burgos & González Rebollar, and is shown in Figure 3.

An analysis of the diagram reveals that:

- *free bioclimatic intensity - warm type* (*IBLc*) is present from January to May and from August to December, when the amount of water available in the soil for vegetation is higher than the *residual evapotranspiration* (*e*)
- *dry bioclimatic intensity - warm type* (*IBSc*) is found, by contrast, in the period when the *IBLc* is null, i.e. in July, when the amount of water available in the soil for vegetation is less than *e*
- *conditioned bioclimatic intensity - warm type* (*IBCc*) occurs only in August, when the plants reacquire the cell turgidity they had lost due to the pronounced aridity of the previous months.

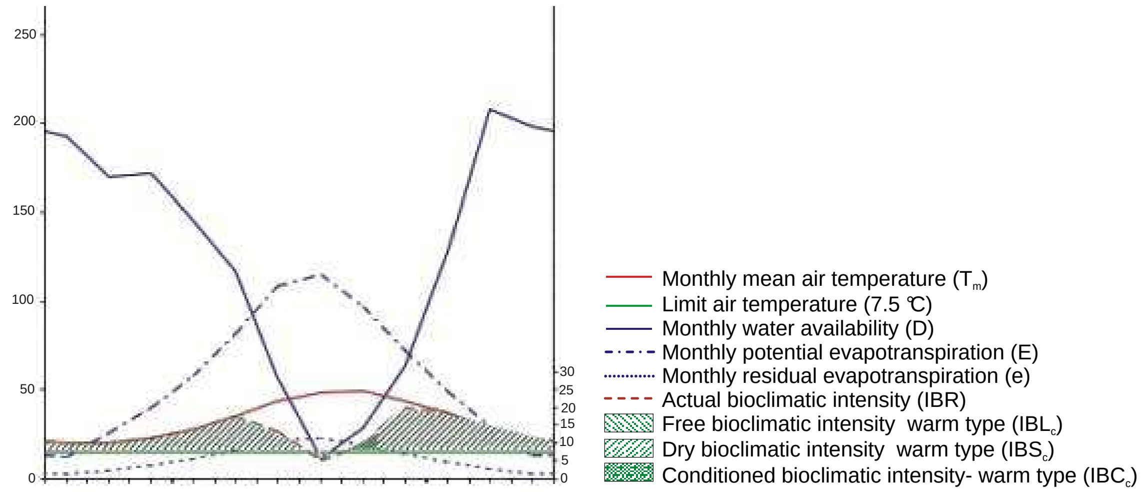


Fig. 3. Bioclimatic diagram, drawn up using the methods proposed by Montero de Burgos & González Rebollar, for the Otranto weather station.

## Pedological characteristics

In the study area, soils have formed (Aru et al., 1982) which are classified by the U.S.D.A. Soil Taxonomy as belonging to the order of *Vertisols*, suborder *Xererts*.

These are soils with an A/C profile, dark brown in colour, made up of a succession of mineral horizons rich in humified organic matter.

Their texture is moderately fine and sandy-clayey-loam; their pH varies from neutral to sub-alkaline.

Due to their high clay content, these soils tend to swell in autumn and winter and crack during the summer.

Drainage reduces with depth, down to no more than 1.2 m, and overall occurs rather slowly.

## Vegetational characteristics

A census of the spontaneous vegetation in the study area has shown the presence of forests of Holm Oak (*Quercus ilex* L.) maquis-forests of Strawberry tree (*Arbutus unedo* L.) and Kermes Oak, as well as maquis and garrigue which are stages of degeneration of these woodlands. Both are sources for the dispersal of propagules from species involved in the naturalisation of the pine forests in the survey.

*Erica manipuliflora*

The Holm Oak forests include one at Specchiulla, where there are many ancient fully-grown trees. The forest is made up of Holm Oaks, the dominant species, in association with:

- Wild Olive, in the tree layer
- Phillyrea and Kermes Oak, the latter scattered in areas with rocky outcrops, in the arborescent layer
- Mediterranean Buckthorn, Bay Laurel (*Laurus nobilis* L.), Lentisk and Butcher's Broom, in the shrub layer
- Wood Asparagus (*Asparagus acutifolius* L.), Spring Cyclamen (*Cyclamen repandum* S. et S.), Ivy (*Hedera helix* L.), Wild Madder (*Rubia peregrina* L.) and Italian Sarsaparilla, in the herbaceous and vertical layers.

This is a plant community with an uneven-aged stand structure, quite rare for the Mediterranean region. It can be attributed to the *Viburno-Quercetum ilicis* Br. Bl. 1936, em. Rivas-Martinez 1975 community, belonging to the *Quercion ilicis* Br. Bl. 1936 alliance.

*Arbuto-Quercetum cocciferae*

The maquis-forests include one - located just coastward of the pine plantation stands - which had been cut back in the past to become a coppice with standards, but has not recently been subjected to coppicing. It is made up of:

- Wild Olive and Kermes Oak, which are old reserve trees, in association with Service tree (*Sorbus domestica* L.)
- Mediterranean Buckthorn, Tree Heather (*Erica arborea* L.) and Apulian Heather (*Erica manipuliflora* Salisb.).

The community described has previously been identified (Brullo et al., 1986) as the *Arbuto-Quercetum cocciferae* association, in the *Oleo-Ceratonion* Br. Bl. 1936, em. Rivas-Martinez 1975 alliance.

**Biometrical and silvicultural characteristics**

The demographic and biometric characteristics of the pine plantation stands were analysed, as mentioned above, in 23 study plots, for the same number of sample populations, each with different levels of naturalisation.

Table 1 shows tree populations, indicating for each study plot and class the per-hectare values for each parameter. Analysis shows that as naturalisation increases:

- the number of trees decreases significantly: the mean value of the classes drops by 200 units, or 38%, from th first to the last. Of course, the mean distance between the trees increases;
- the dominant height decreases, though very little;
- the *Spacing Index* (*s% = 100xdist./Hdom*) is much greater: there is an approximately 44% difference between the mean values in the first and last classes;
- the basal area decreases: there is a roughly 25% difference between the comparable values
- crown cover decreases slightly: there is a difference of about 10% between the top and bottom values.

Table 1. Values for the demographic and biometrical parameters in the tree populations, distinguished by study plot and naturalisation class.

| Naturalisation class | Study plot | Number of trees | Mean distance between trees | Hd | Spacing Index | Basal area | Crown cover |
|---|---|---|---|---|---|---|---|
| | n. | n/ha | m | m | % | $m^2$/ha | $m^2$/ha |
| 1 | 1 | 594 | 4,10 | 18,2 | **22,54** | 34,94 | 9527 |
| 1 | 22 | 524 | 4,37 | 17,9 | **24,41** | 32,01 | 9438 |
| 1 | 23 | 481 | 4,56 | 18,9 | **24,12** | 31,45 | 9373 |
| **Mean values** | | **533** | **4,34** | **18,3** | **23,69** | **32,80** | **9446** |
| 2 | 7 | 481 | 4,56 | 17,0 | **26,82** | 37,77 | 9286 |
| 2 | 14 | 410 | 4,94 | 18,0 | **27,44** | 34,64 | 9561 |
| 2 | 15 | 552 | 4,26 | 15,7 | **27,11** | 34,25 | 9522 |
| 2 | 6 | 481 | 4,56 | 17,0 | **26,82** | 34,63 | 9201 |
| 2 | 18 | 467 | 4,63 | 17,1 | **27,06** | 33,26 | 8929 |
| 2 | 4 | 524 | 4,37 | 15,9 | **27,47** | 34,14 | 9145 |
| **Mean values** | | **486** | **4,55** | **16,8** | **27,12** | **34,78** | **9274** |
| 3 | 17 | 453 | 4,70 | 16,4 | **28,65** | 29,24 | 9188 |
| 3 | 2 | 368 | 5,21 | 17,5 | **29,79** | 31,23 | 9073 |
| 3 | 11 | 410 | 4,94 | 17,2 | **28,71** | 27,39 | 8493 |
| 3 | 5 | 396 | 5,03 | 17,7 | **28,39** | 31,77 | 9173 |
| **Mean values** | | **407** | **4,97** | **17,2** | **28,89** | **29,91** | **8982** |
| 4 | 19 | 368 | 5,21 | 16,1 | **32,38** | 26,99 | 9062 |
| 4 | 16 | 340 | 5,42 | 17,9 | **30,30** | 27,44 | 8865 |
| 4 | 9 | 425 | 4,85 | 15,7 | **30,90** | 26,76 | 8723 |
| 4 | 12 | 368 | 5,21 | 16,4 | **31,79** | 23,52 | 8833 |
| 4 | 8 | 368 | 5,21 | 16,4 | **31,79** | 23,95 | 8794 |
| 4 | 3 | 368 | 5,21 | 16,6 | **31,40** | 27,23 | 8957 |
| **Mean values** | | **373** | **5,19** | **16,5** | **31,41** | **25,73** | **8856** |
| 5 | 10 | 354 | 5,31 | 15,3 | **34,74** | 23,01 | 8627 |
| 5 | 13 | 354 | 5,31 | 15,9 | **33,43** | 23,90 | 8790 |
| 5 | 20 | 297 | 5,80 | 16,8 | **34,54** | 26,82 | 8673 |
| 5 | 21 | 326 | 5,54 | 16,4 | **33,77** | 24,46 | 8248 |
| **Mean values** | | **333** | **5,49** | **16,1** | **34,12** | **24,55** | **8585** |

Figures 4, 5 and 6 show a system of Cartesian axes with the per-hectare values for the numbers of trees, basal area and crown cover, respectively, correlated with the *Spacing Index* values, for each study plot and class.

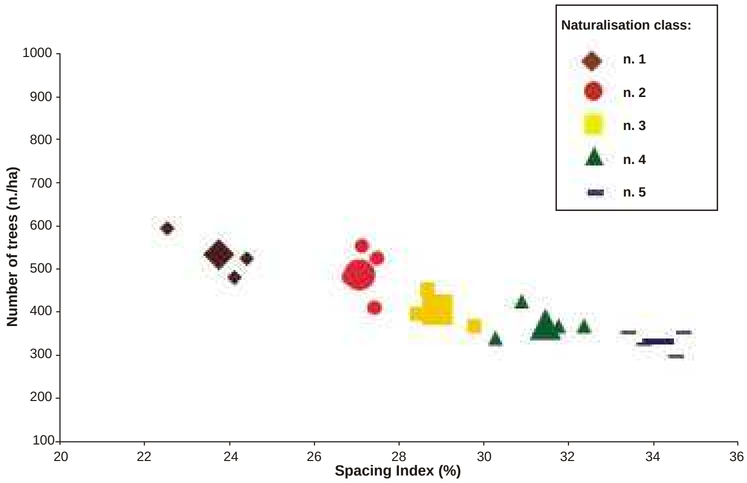


Fig. 4. Variation in the number of trees per hectare as a function of the Hart-Becking *Spacing Index*, for each study plot and naturalisation class

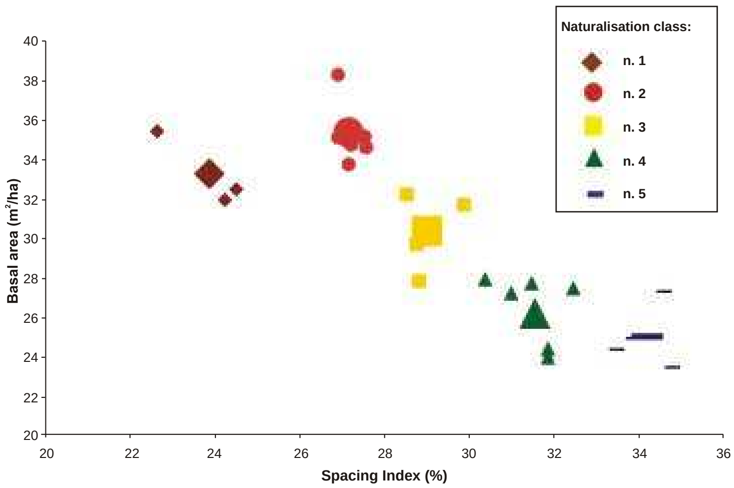


Fig. 5. Variation in the basal area per hectare as a function of the Hart-Becking *Spacing Index*, for each study plot and naturalisation class.

This serves to ascertain whether the *Spacing Index* is correlated with the level of naturalisation in these pine forests.

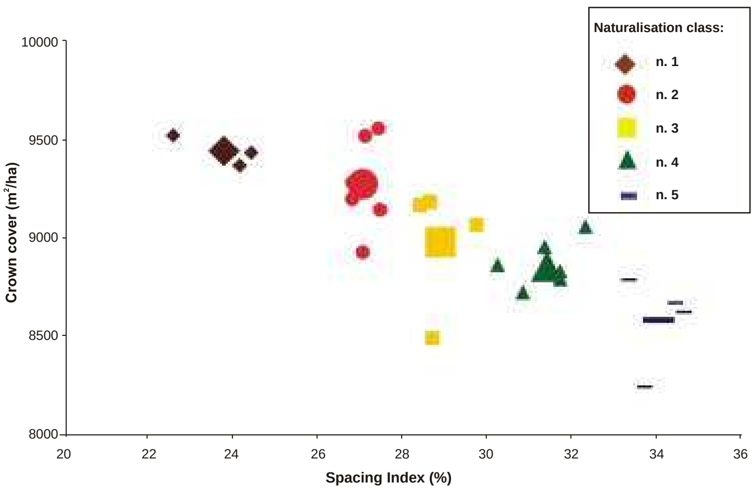


Fig. 6. Variation in the crown cover per hectare as a function of the Hart-Becking *Spacing Index*, for each study plot and naturalisation class.

Analysis of Table 1 and the figures shows that a correlation does indeed exist.

The *Spacing Index* is proportional to the level of naturalisation, not only in its mean values for each class, but also in those for each study plot, which by contrast is not the case for each parameter.

Table 2 shows the values in the shrub population, for the same study plots and classes, of the number of elements per m$^2$, their mean height and the *Regeneration Index*.

Table 2. Values for the demographic and biometrical parameters in the shrub populations, distinguished by study plot and naturalisation class.

| Naturalisation class | Study Plot n. | Shrubs Individuals n./m$^2$ | Mean height m | Regeneration Index |
|---|---|---|---|---|
| 1 | 1 | 6 | 0,29 | 1,85 |
| 1 | 22 | 0 | 0,17 | 0,07 |
| 1 | 23 | 0 | 0,03 | 0,00 |
| **Mean values** | | **2** | **0,16** | **0,64** |
| 2 | 7 | 11 | 0,48 | 5,39 |
| 2 | 14 | 2 | 0,44 | 0,92 |
| 2 | 15 | 11 | 0,34 | 3,60 |
| 2 | 6 | 51 | 0,13 | 6,81 |
| 2 | 18 | 13 | 0,51 | 6,49 |
| 2 | 4 | 16 | 0,45 | 6,93 |
| **Mean values** | | **17** | **0,39** | **5,02** |
| 3 | 17 | 17 | 0,42 | 7,31 |
| 3 | 2 | 15 | 0,42 | 6,19 |
| 3 | 11 | 25 | 0,79 | 19,58 |
| 3 | 5 | 23 | 0,57 | 13,28 |
| **Mean values** | | **20** | **0,55** | **11,59** |
| 4 | 19 | 13 | 0,48 | 6,21 |
| 4 | 16 | 26 | 0,53 | 13,91 |
| 4 | 9 | 28 | 0,55 | 15,50 |
| 4 | 12 | 23 | 0,58 | 13,58 |
| 4 | 8 | 26 | 0,67 | 17,28 |
| 4 | 3 | 23 | 0,70 | 15,86 |
| **Mean values** | | **23** | **0,58** | **13,72** |
| 5 | 10 | 24 | 0,76 | 18,65 |
| 5 | 13 | 25 | 0,64 | 16,21 |
| 5 | 20 | 15 | 0,82 | 11,89 |
| 5 | 21 | 16 | 1,18 | 19,39 |
| **Mean values** | | **20** | **0,85** | **16,53** |

The data demonstrate that this Index increases significantly with the level of naturalisation.

Figure 7 shows a system of Cartesian axes with the values for the *Spacing* and *Regeneration Indices* for each study plot and class.

The Table and Figure demonstrate that even though the values in the *Regeneration Index* grow together with naturalisation, they vary significantly within the classes themselves.

Indeed, quite small changes in the *Regeneration Index* correspond to different classes of naturalisation.

## CONCLUSIONS

This paper has shown that the most significant parameter in the naturalisation processes occurring in these pine forests is the Hart-Becking *Spacing Index*.

Even though this index was devised, as is known, to define the intensity of thinning required in specialised timber stands, it can also take on a further meaning, connected with ecological features.

It has proved to be effective at defining the level of naturalisation in these pine forests, and this can probably be extended to other woodlands. It has also proved to be useful for defining the intensity of thinning operations required to encourage naturalisation.

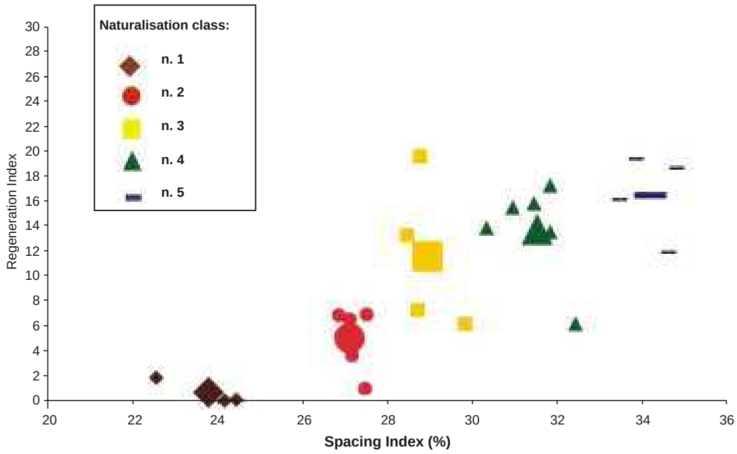


Fig. 70. Variation in the Magini *Regeneration Index* as a function of the Hart-Becking *Spacing Index*, for each study plot and naturalisation class.

The results of this survey must of course be verified in other areas within Apulia and elsewhere, for plantation stands of Aleppo Pine and other Mediterranean pines.

Furthermore, the functionality of our experimental method  currently still in a proposal phase  needs to be verified.

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