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## MAP-MAKING OF PLANT BIOMASS AND LEAF AREA INDEX FOR MANAGEMENT OF PROTECTED AREAS

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### ABSTRACT

An inventory of the vegetation types of Castelporziano Estate (Rome), including examples of Mediterranean ecosystems in excellent preserved condition, was compiled. Because Leaf Area Index (LAI) changed with forest structure and developmental stages, maximum LAI provided a good estimate of maximum biomass accumulation. Plant biomass estimation, ranging from 61 tons ha<sup>-1</sup> to 360 tons ha<sup>-1</sup>, fitted well into 14 biomass classes; the highest values (from 301 tons ha<sup>-1</sup> to 360 tons ha<sup>-1</sup>) were related to stratified forested vegetation types, including the more mature *Pinus pinea* plantations, *Quercus ilex* evergreen forests and broadleaf mixed forests. LAI ranged from 0.5 to 4.5, and changed with forest structure, increasing with the increase of plant biomass. Leaf area index measurements fitted well into nine LAI classes, and the highest values were related to the stratified vegetation types. Biomass and LAI maps might be employed as a computerised mapped information system for natural resource policy, regional planning, and landscape management. Long-term monitoring may easily be achieved by LAI measurements which can be converted to biomass values by the identified relationship between plant biomass and LAI.

Key words: LAI, landscape management, map-making, plant biomass.

### INTRODUCTION

New vision of landscape ecology requires long-term research to understand the dynamic of ecosystems, and management can be defined as an activity for achieving specific conservation goals according to natural, seminatural, or cultivated resources. In order to achieve this it is necessary to survey the current and the potential inventories of species and ecosystems (Safriel et al. 1997) that provide information on the status of ecosystems giving a sense of the resources dynamics (Halvorson and Maender 1994; Halvorson 1998).

Landscape can be thought as a mosaic in different stages of recovery from natural disturbances. Changes in plant and stand processes are in fact mediated by the local state of disturbance and one would expect that variation in structure could have the effect of altering processes in terrestrial ecosystems (Shugart et al. 1997). For instance, canopy structure changes influence both absolute stem growth and the efficiency of this growth (Jack and Long 1991). Several reports (Wittwer 1983; Botkin 1986; Pierce and Running 1988; Gratani 1997; Gratani and Foti 1998) identify leaf area index (LAI) as the most important variable for characterising vegetation structure and functioning for global researches, including estimation of plant productivity and determination of canopy cover densities (Kaufmann and Troendle 1981). Since LAI

changes with forest structure and developmental stages, maximum LAI at forest maturity is a good estimator of maximum biomass accumulation (Waring 1983; Gratani and Fiorentino 1988; Shao et al. 1995).

New sensitivity tests carried out on vegetation indicate that climate-induced increases in disturbance could significantly alter plant species composition of forests and plant biomass (Overpeck et al. 1990). Long-term monitoring of ecosystems is important in order to establish the tolerance threshold to perturbations. One basic type of quality evaluation procedure is the use of potential productivity based on the present state of the resources (Naveh and Lieberman 1990). Landscape units could be expressed as functional parameters of production, regulation, protection, and information functions (Naveh 1991).

The main objective of this research was to effect map-making of natural, seminatural, and cultivated units inside a protected Estate, including examples of Mediterranean ecosystems which have been preserved in excellent condition. This required long-term monitoring programs aimed at determining community composition, structure, and biomass changes over time. Landscape management ideally must start with inventories and maps based on research data giving information on status and trends (Halvorson 1998; Halvorson and Maender 1994). According to Shao et al. (1995) we constructed these maps considering that:

1) plant biomass is related to plant size and density; 2) leaf area index for a stand is the summation of LAI of all the species in the stand and it is related to species composition and stand density; and 3) plant height is a better indicator of site conditions.

#### MATERIALS AND METHODS

##### *Study Area and Climate*

The study was carried out in the presidential Estate of Castelporziano (SSW of Rome, Italy; lat 41°45'N, long 12°26'E). It covers ca. 4700 ha, including different vegetation types (Fig. 1): psammophilous vegetation developed along the coast (20 ha), low maquis (54 ha), high maquis (580 ha), *Quercus ilex* L. evergreen forests (255 ha), *Quercus suber* L. evergreen forests (460 ha), *Pinus pinea* L. plantations (678 ha), broadleaf mixed forests (2132 ha), *Eucalyptus globulus* Labill. plantations (73 ha), grassland (225 ha) and agricultural areas (175 ha).

Climatic data were provided by the Meteorological Station inside the Estate (average for the years 1985–1997). Total rainfall was 775 mm, most of it falling from January to April and from October to December. Maximum and minimum annual air temperatures averaged 21 C and 10 C, respectively.

##### *Stand Structure, Plant Biomass and LAI*

Field measurements were carried out during 1995–1997. Measurements of structure and plant biomass included: plant height, plant stem diameter at the base and diameter at breast height, stand density and leaf area index (LAI). Twenty sample areas, 200 m<sup>2</sup> each, were established, respectively, in the low maquis and in the high maquis; twenty, 400 m<sup>2</sup> each, in the *Eucalyptus globulus* plantations, *Quercus ilex* and *Quercus suber* evergreen forests, *Pinus pinea* plantations, and broadleaf mixed forests, according to Newbould (1967) and Aber (1979). Twenty-five areas, 1 m<sup>2</sup> each, were established, respectively, in psammophilous vegetation and in the grassland (Singh et al. 1975).

Nondestructive measurements were carried out in

the sample areas. All plants in each area were measured and divided into diameter classes. Destructive measurements were carried out in three subsample areas for vegetation type (25 m<sup>2</sup> each in the maquis, and 100 m<sup>2</sup> each in the forests and plantations). Three representative plants of each species in each class were cut at random inside the destructive areas and subdivided into stem, branches, and leaves. They were weighed in the field for total fresh weights and subsampled to enable conversion to a dry-weight basis. Subsamples were oven-dried at 105 C to constant weight, and the conversion of field fresh weight to dry weight was carried out by the ratio of dry weight to fresh weight in the subsamples, according to Bunce (1968) and Stewart et al. (1979). Dry weights of the harvested plants for each diameter class were multiplied for the total number of individuals in each class to obtain stand biomass, according to Ovington and Pearsall (1956) and Whittaker and Marks (1975).

Grassland and psammophilous vegetation sampling was carried out by harvesting all plant material at soil level. Collections were oven dried and weighed according to Singh et al. (1975).

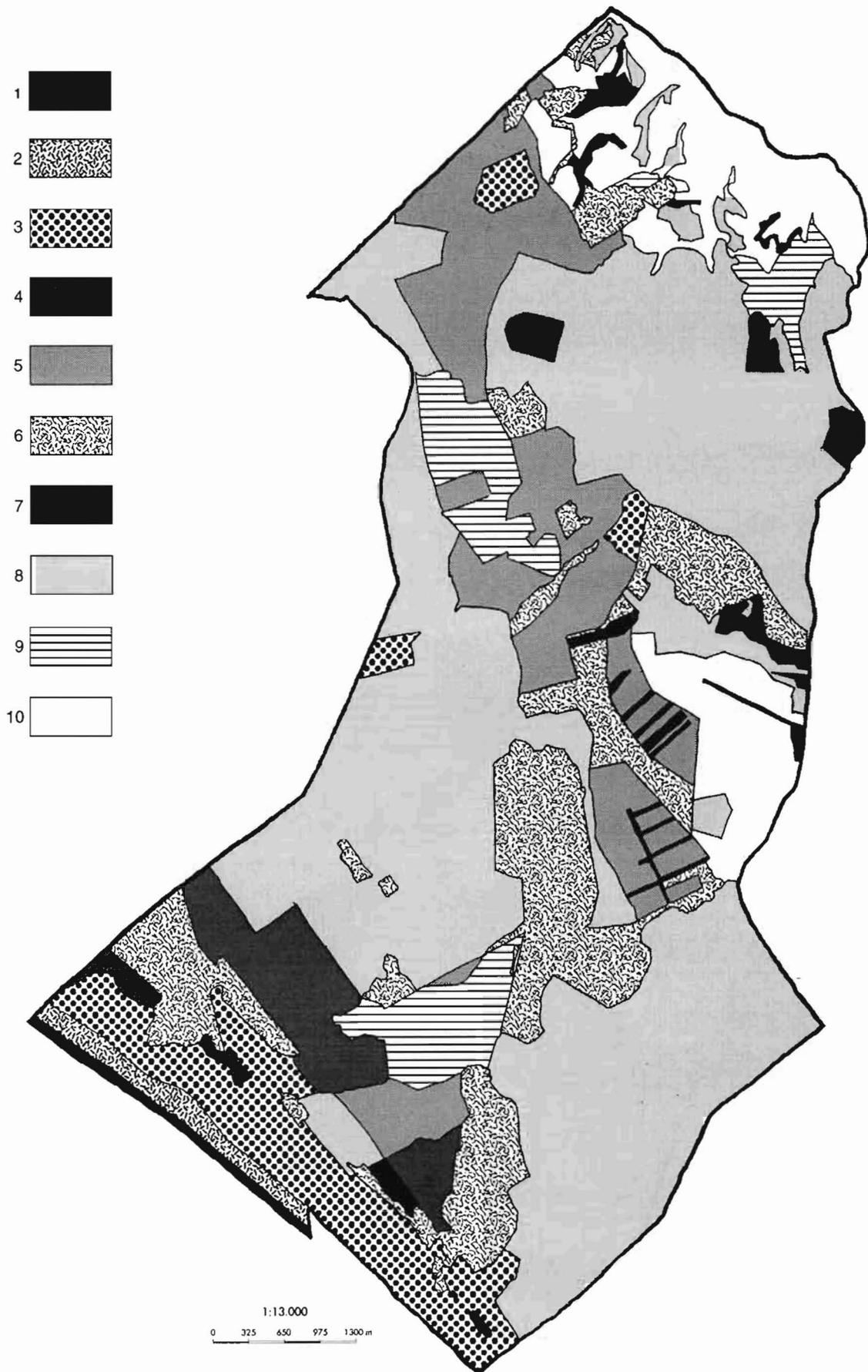
Leaf area index was estimated using the “LAI 2000 Plant Canopy Analyzer” (LI-COR Inc., Lincoln, Nebraska, USA), according to Waring (1985), Gower and Norman (1991), Welles and Norman (1991), Stenberg et al. (1994), Brenner et al. (1995) and Welles and Cohen (1996). We applied the correction factor (R = 0.57) proposed by Stenberg et al. (1994) for conifer canopies.

##### *Thematic Maps Elaboration*

Thematic maps were produced using these basic key words: 1) physical space, i.e., the space in which there is a concrete ecosystem; 2) time, i.e., the particular instant at which the ecosystem exists; and 3) dry matter, i.e., the mass occupying the physical space, according to Miller (1975), Naveh and Lieberman (1990). Excel for Windows program and Adobe Illustrator for Mac Intosh program were used for constructing the maps.

Fig. 1. Distribution of vegetation types in the Castelporziano Estate (Rome).

- 1 = Psammophilous vegetation.
- 2 = Low maquis with local dominance of *Quercus ilex*, *Pistacia lentiscus*, *Erica arborea*, *E. multiflora*, *Phillyrea latifolia*, *Arbutus unedo*, *Cistus incanus*, *Smilax aspera*.
- 3 = High maquis dominated by *Quercus ilex*, *Pistacia lentiscus*, *Erica arborea*, *Phillyrea latifolia*, *Arbutus unedo*, *Myrtus communis*, *Smilax aspera*.
- 4 = *Quercus ilex* evergreen forests.
- 5 = *Quercus suber* evergreen forests.
- 6 = *Pinus pinea* plantations.
- 7 = *Eucalyptus globulus* plantations.
- 8 = Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.
- 9 = Grassland dominated by *Verbascum sinuatum*, *Daucus carota*, *Ranunculus bulbosus*, *Dasyphyrum villosum*, *Avena barbata*, *Dactylis glomerata*, *Asphodelus microcarpus*.
- 10 = Agricultural areas.



### Regression Analysis

Excel for Windows program was used for regression analysis.

## RESULTS

### Plant Biomass Map and LAI Map

Plant biomass estimates were used to compile the "Plant Biomass Map of Castelporziano" (Fig. 2). The data were classified into 14 biomass classes which were coded accordingly. This Map showed the distribution of quantitative data (dry weight/soil surface area) on the Estate. The first class showed biomass values lower than 1 ton ha<sup>-1</sup>; the second class 1–5 tons ha<sup>-1</sup>; the third 6–30 tons ha<sup>-1</sup>; the fourth 31–60 tons ha<sup>-1</sup>; the fifth 61–90 tons ha<sup>-1</sup>; the sixth 91–120 tons ha<sup>-1</sup>; the seventh 121–150 tons ha<sup>-1</sup>, the eighth 151–180 tons ha<sup>-1</sup>, the ninth 181–210 tons ha<sup>-1</sup>, the tenth

211–240 tons ha<sup>-1</sup>, the eleventh 241–270 tons ha<sup>-1</sup>, the twelfth 271–300 tons ha<sup>-1</sup>, the thirteenth 301–330 tons ha<sup>-1</sup>, and the fourteenth 331–360 tons ha<sup>-1</sup>.

The LAI data were grouped into nine classes, which were coded (Fig. 3) as follows: the first class showed LAI values less than 0.5; the second class varied from 0.6 to 1.0, the third 1.1–1.5, the fourth 1.6–2.0, the fifth 2.1–2.5, the sixth 2.6–3.0, the seventh 3.1–3.5, the eighth 3.6–4.0, and the ninth 4.1–4.5.

### Psammophilous Vegetation

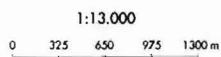
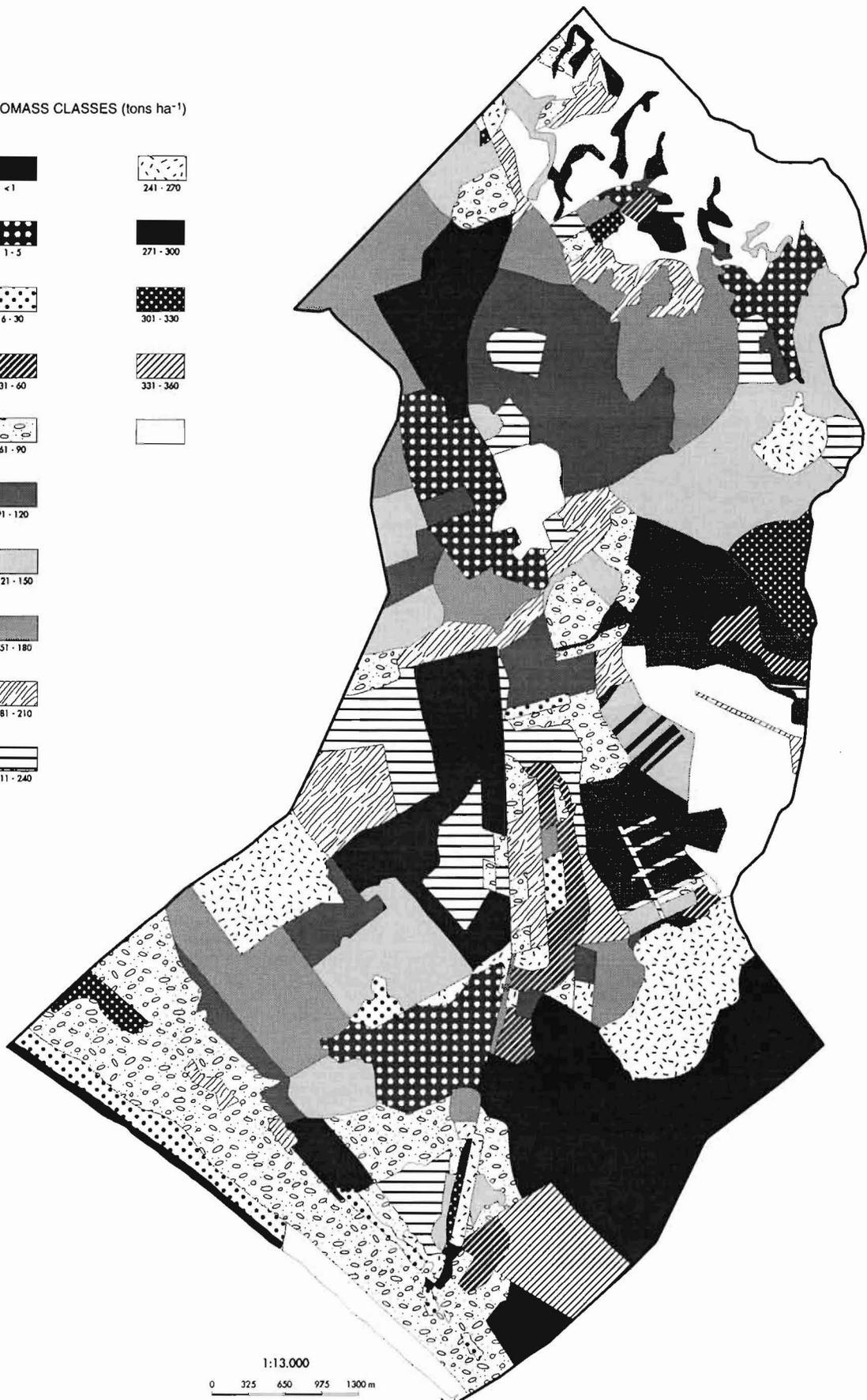
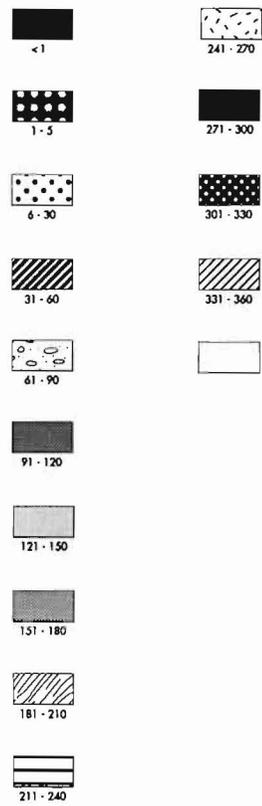
After the aphytoic area, the first community consisted mainly of therophytes (*Cakile maritima* Scop., *Euphorbia peplis* L. and *Salsola kali* L.). The second community was the *Agropyretum mediterraneum* (Kuhn.- Lord.) Braun-Blanq. 1933 composed by *Agropyron junceum* (L.) P. Beauv. ssp. *mediterraneum* Simonet et Guin., *Sporobolus pungens* (Schreb.)

→

Fig. 2. Plant biomass map of Castelporziano Estate (Rome). Plant biomass classes (tons ha<sup>-1</sup>) are shown, each class is coded.

- <1 = Psammophilous vegetation.
- 1–5 = Grassland dominated by *Verbascum sinuatum*, *Daucus carota*, *Ranunculus bulbosus*, *Dasyphyrum villosum*, *Avena barbata*, *Dactylis glomerata*, *Asphodelus microcarpus*.
- 6–30 = *Pinus pinea* plantations.  
Low maquis with local dominance of *Quercus ilex*, *Pistacia lentiscus*, *Erica arborea*, *E. multiflora*, *Phillyrea latifolia*, *Arbutus unedo*, *Cistus incanus*, *Smilax aspera*.
- 31–60 = *Pinus pinea* plantations.  
*Eucalyptus globulus* plantations.
- 61–90 = *Pinus pinea* plantations.  
*Eucalyptus globulus* plantations.  
High maquis dominated by *Quercus ilex*, *Pistacia lentiscus*, *Erica arborea*, *Phillyrea latifolia*, *Arbutus unedo*, *Myrtus communis*, *Smilax aspera*.  
*Quercus suber* evergreen forests.
- 91–120 = *Pinus pinea* plantations.  
*Eucalyptus globulus* plantations.  
*Quercus suber* evergreen forests.  
Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.
- 121–150 = *Pinus pinea* plantations.  
*Eucalyptus globulus* plantations.  
*Quercus suber* evergreen forests.  
Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.  
*Quercus ilex* evergreen forests.
- 151–180 = *Pinus pinea* plantations.  
*Eucalyptus globulus* plantations.  
*Quercus suber* evergreen forests.  
Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.  
*Quercus ilex* evergreen forests.
- 181–210 = *Pinus pinea* plantations.  
*Eucalyptus globulus* plantations.  
*Quercus suber* evergreen forests.  
Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.  
*Quercus ilex* evergreen forests.
- 211–240 = *Pinus pinea* plantations.  
*Eucalyptus globulus* plantations.  
Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.  
*Quercus ilex* evergreen forests.
- 241–270 = *Pinus pinea* plantations.  
Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.
- 271–300 = *Pinus pinea* plantations.  
Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.
- 301–330 = *Pinus pinea* plantations.  
Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.  
*Quercus ilex* evergreen forests.
- 301–330 = Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber* L.
- = Not monitored.

BIOMASS CLASSES (tons ha<sup>-1</sup>)



Kunth, and *Cyperus kalli* (Forssk.) Murb. The third community was the *Ammophiletum arundinaceae* Braun-Blanq. 1933 in which the process of dunes consolidation was marked essentially by *Ammophila littoralis* (P. Beauv.) Rothm., *Echinophora spinosa* L., *Ononis variegata* L., and *Medicago marina* L. The *Crucianelletum maritimae* Braun-Blanq. 1933 was the inland community on the dunes of Castelporziano. *Crucianella maritima* L. and *Pancratium maritimum* L., characteristic species of this association, were distributed in small discontinuous groups. The alliances and the higher hierarchical orders and classes were represented by *Anthemis maritima* L., *Cutandia maritima* (L.) Richt., *Vulpia membranacea* (L.) Link, *Calystegia soldanella* (L.) R. Br., and *Eryngium maritimum* L. Plant height ranged from 5 to 50 cm; the lowest values typical of the creeping and branched species (*Cakile maritima* and *Medicago marina*), while the highest *Ammophila littoralis*, *Eryngium maritimum*, and *Anthemis maritima* made up the largest fraction of the total plant biomass (30.2 g m<sup>-2</sup>) 7%, 41 %, and 20%, respectively.

#### Low and High Mediterranean Maquis

Low maquis was 1.0 ± 0.5 m high and characterized by 2.5 LAI (Tab. 1), with dominance of *Quercus ilex*, *Pistacia lentiscus* L., *Erica arborea* L., *Erica multiflora* L., *Phillyrea latifolia* L., *Arbutus unedo* L., *Cistus incanus* L., and *Smilax aspera* L. A large part of the total biomass was accounted for by *Quercus ilex*, *Phillyrea latifolia*, and *Arbutus unedo*, 27%, 14%

and 15%, respectively. Leaf biomass was 24% of total biomass (19 tons ha<sup>-1</sup>). The above-ground biomass estimates were comparable to those of other Mediterranean shrub communities reported by Lossaint (1973), Margaris (1976), Mooney and Rundel (1979), and Merino and Vicente (1981).

High maquis was characterised by 3.0 ± 1.5 m high shrubs (Tab. 1), and it was dominated by *Quercus ilex*, *Pistacia lentiscus*, *Erica arborea*, *Phillyrea latifolia*, *Arbutus unedo*, *Myrtus communis* L. and *Smilax aspera*. *Erica arborea* accounted for most of the total biomass (55%). Leaf biomass was 10% of the total biomass. Plant biomass and LAI increased from low to high maquis (2.5 and 4.3, respectively).

#### *Quercus ilex* Evergreen Forests

*Quercus ilex* evergreen forests were grouped into five biomass classes (Fig. 2). The above-ground biomass estimates were within the range of values of other holm-oak forests described by Lossaint and Rapp (1971), Bruno et al. (1976), Leonardi and Rapp (1982), and Lledo et al. (1992): the lowest biomass class (121–150 tons ha<sup>-1</sup>) grouped forests characterised by a monostatified woody layer and the highest biomass class (301–330 tons ha<sup>-1</sup>) were multistatified communities (Tab. 2). These communities had a tree layer composed of *Quercus ilex*, 16.2 ± 2 m high, and a shrub layer, 3.7 ± 0.8 m high, with an abundance or *Quercus ilex*, *Phillyrea latifolia*, and *Pistacia lentis-*

Fig. 3. Leaf area index (LAI) map of Castelporziano Estate (Rome). LAI classes are shown, each class is coded.

- 
- ≤0.5 = *Pinus pinea* plantations.
  - 0.6–1.0 = *Pinus pinea* plantations.  
Grassland dominated by *Verbascum sinuatum*, *Daucus carota*, *Ranunculus bulbosus*, *Dasyphyrum villosum*, *Avena barbata*, *Dactylis glomerata*, *Asphodelus microcarpus*.
  - 1.1–1.5 = *Pinus pinea* plantations.  
Grassland dominated by *Verbascum sinuatum*, *Daucus carota*, *Ranunculus bulbosus*, *Dasyphyrum villosum*, *Avena barbata*, *Dactylis glomerata*, *Asphodelus microcarpus*.  
*Eucalyptus globulus* plantations.
  - 1.6–2.0 = *Pinus pinea* plantations.  
Grassland dominated by *Verbascum sinuatum*, *Daucus carota*, *Ranunculus bulbosus*, *Dasyphyrum villosum*, *Avena barbata*, *Dactylis glomerata*, *Asphodelus microcarpus*.  
*Quercus suber* evergreen forests.
  - 2.1–2.5 = *Pinus pinea* plantations.  
*Quercus suber* evergreen forests.  
Low maquis with local dominance of *Quercus ilex*, *Pistacia lentiscus*, *Erica arborea*, *E. multiflora*, *Phillyrea latifolia*, *Arbutus unedo*, *Cistus incanus*, *Smilax aspera*.
  - 2.6–3.0 = *Pinus pinea* plantations.  
Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.
  - 3.1–3.5 = Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.  
High maquis dominated by *Quercus ilex*, *Pistacia lentiscus*, *Erica arborea*, *Phillyrea latifolia*, *Arbutus unedo*, *Myrtus communis*, *Smilax aspera*.
  - 3.6–4.0 = Broadleaf mixed forests dominated by *Quercus frainetto*, *Q. cerris*, *Q. pubescens*, *Q. suber*.  
*Quercus ilex* evergreen forests.
  - 4.1–4.5 = High maquis dominated by *Quercus ilex*, *Pistacia lentiscus*, *Erica arborea*, *Phillyrea latifolia*, *Arbutus unedo*, *Myrtus communis*, *Smilax aspera*.  
*Quercus ilex* evergreen forests.
  - = Not monitored.

LAI CLASSES



$\le 0.5$



0.6-1.0



1.1-1.5



1.6-2.0



2.1-2.5



2.6-3.0



3.1-3.5



3.6-4.0



4.1-4.5



> 4.5

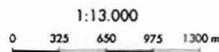
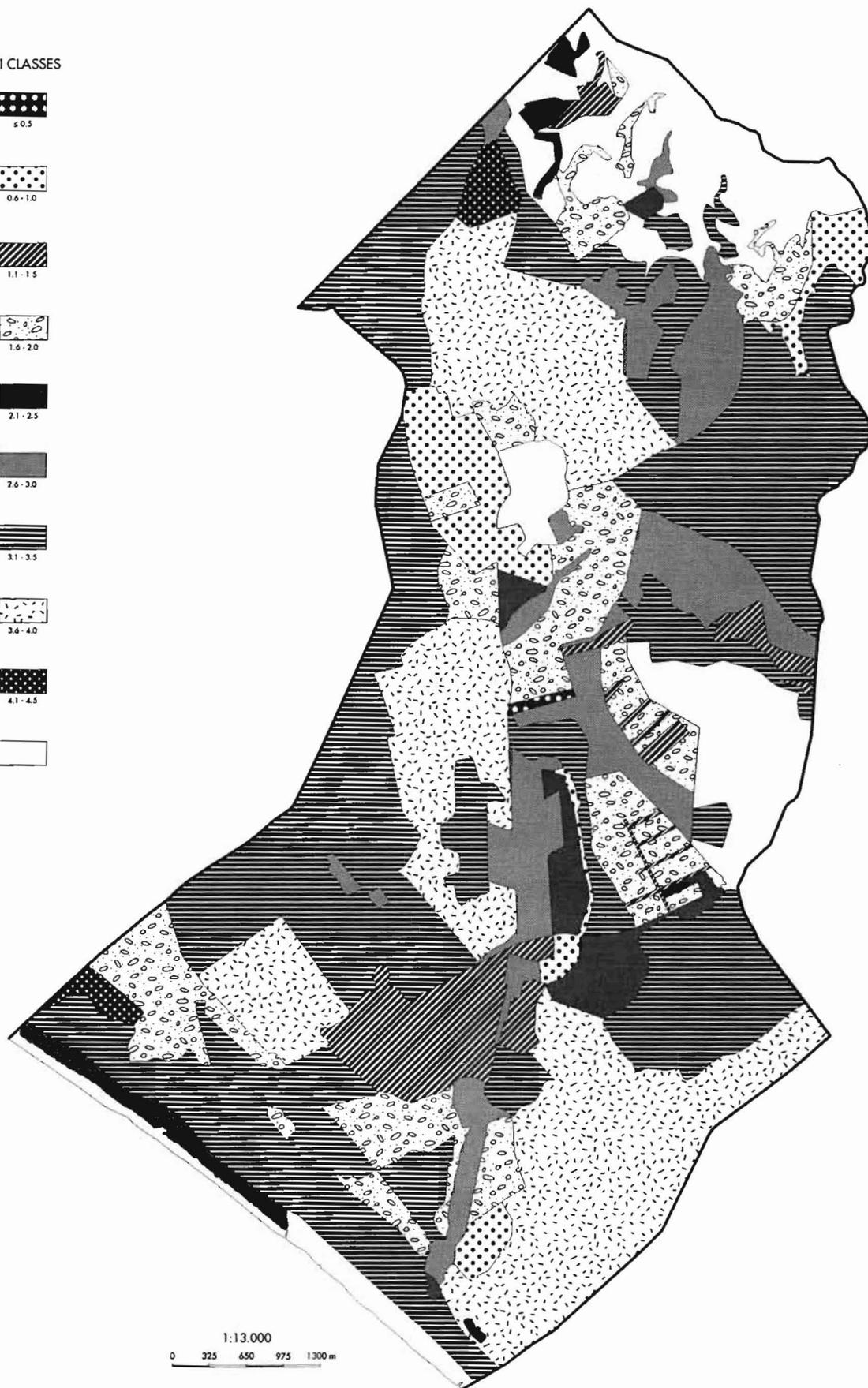


Table 1. Structural characteristics of low maquis and high maquis and biomass classes. Means of plant height  $\pm$  standard deviations are shown.

	Low maquis	High maquis
Plant height m	1.0 $\pm$ 0.5	3.0 $\pm$ 1.5
LAI classes	2.1–2.5	3.1–4.5
Biomass classes tons ha <sup>-1</sup>	6–30	61–90

*cus*. The shrub layer accounted for 83% of the total plant density. The herb layer was poorly developed and included *Cyclamen repandum* Sibth. et Sm., *Alliaria petiolata* (M. Bieb.) Cavara et Grande, *Brachypodium sylvaticum* (Huds.) P. Beauv., and *Asperula laevigata* L. This stratified system provided a good example of dense canopies (Gratani 1997). LAI ranged from 3.6 to 4.5 and the highest values were found in the most complex multistratified stands. LAI of mature *Quercus ilex* forests could reach values above 4 in more mesic stands (Eckardt et al. 1977; Joffre et al. 1996).

#### *Quercus suber* Forests

These forests were examples of seminatural systems in the Estate, where the species was naturally present but the density of the stands was controlled by periodic cuttings. They were grouped into five biomass classes, according to stand density (Tab. 3). The lower cork-oaks (4.8  $\pm$  0.7 m in height, 7.8  $\pm$  0.8 m<sup>2</sup> ha<sup>-1</sup> total basal area) belong to the 61–90 tons ha<sup>-1</sup> biomass class, similar to that studied by Leonardi et al. (1992) for a natural *Quercus suber* forest in Sicily. The forest LAI ranged from 1.6 to 2.5.

#### *Pinus pinea* Plantations

A large part of the Estate was occupied by *Pinus pinea* plantations of different density and age, most of them 31–120 years old. Plant height ranged from 1.9  $\pm$  0.6 m (corresponding to an 11-year-old stand) to 22.6  $\pm$  0.3 m (corresponding to an over 100-year-old stand) (Tab. 4). Total biomass, distributed in 11 classes

Table 3. Structural characteristics of *Quercus suber* evergreen forests and biomass classes. Means of plant density, plant height, and total basal area  $\pm$  standard deviations are shown.

Biomass classes tons ha <sup>-1</sup>	Plant density plant ha <sup>-1</sup>	Height m	Total basal area m <sup>2</sup> ha <sup>-1</sup>
61–90	375 $\pm$ 23	4.8 $\pm$ 0.7	7.8 $\pm$ 0.8
91–120	550 $\pm$ 63	5.5 $\pm$ 0.3	23.2 $\pm$ 0.9
121–150	750 $\pm$ 73	6.1 $\pm$ 1.3	29.6 $\pm$ 2.6
151–180	575 $\pm$ 57	6.6 $\pm$ 0.6	34.9 $\pm$ 1.6
181–210	88 $\pm$ 12	12.4 $\pm$ 0.8	37.9 $\pm$ 0.6

varied from 6 to 30 tons ha<sup>-1</sup> (11-year-old stand) to 301–330 tons ha<sup>-1</sup> (60–100-year-old stand). Young *Pinus pinea* plantations were comparable to those studied by Cabanettes and Rapp (1978). The highest plant density was in the biomass class 6–30 tons ha<sup>-1</sup>. LAI had the highest value (2.6–3.0) in the 301–330 tons ha<sup>-1</sup> biomass class.

#### Broadleaf Mixed Forests

Broadleaf mixed forests were the most extensive vegetation type in the Estate. Stand biomass was in the biomass range of other broadleaf mixed forests in Italy described by Corona et al., (1986) and Gratani and Foti (1998). The values were subdivided into nine biomass classes, according to plant density and species composition (Tab. 5). The dominant tree layer was characterised by *Quercus frainetto* Ten., *Quercus cerris* L., *Quercus pubescens* Willd., and *Quercus suber*.

Local variation of species composition in the shrub-layer of the *Quercus suber* forests contributed to the high variation of plant biomass: the highest biomass values were related to *Carpinus orientalis* Mill. (331–360 tons ha<sup>-1</sup>) and the lowest to Mediterranean maquis shrubs (91–120 tons ha<sup>-1</sup>). LAI ranged from 2.6 to 4.0 and it was in the range measured in Italy by Schirone et al. (1985), Piccoli and Borelli (1988), and Gratani and Foti (1998).

Table 2. Structural characteristics of *Quercus ilex* evergreen forests and biomass classes. Means of plant density, plant height, and total basal area  $\pm$  standard deviations are shown.

Biomass classes tons ha <sup>-1</sup>		Plant density plant ha <sup>-1</sup>	Height m	Total basal area m <sup>2</sup> ha <sup>-1</sup>
121–150	Dominant layer	1675 $\pm$ 45	4.5 $\pm$ 0.7	23.6 $\pm$ 5.7
151–180	Dominant layer	1500 $\pm$ 32	4.7 $\pm$ 0.9	21.1 $\pm$ 3.9
	Dominated layer	3862 $\pm$ 97	3.1 $\pm$ 1.1	2.5 $\pm$ 0.3
181–210	Dominant layer	1100 $\pm$ 40	5.0 $\pm$ 0.3	31.0 $\pm$ 4.1
211–240	Dominant layer	1050 $\pm$ 25	5.5 $\pm$ 0.6	34.6 $\pm$ 3.4
	Dominated layer	1931 $\pm$ 57	2.9 $\pm$ 1.0	1.3 $\pm$ 0.5
301–330	Dominant layer	325 $\pm$ 37	16.2 $\pm$ 2.0	35.9 $\pm$ 2.7
	Dominated layer	1622 $\pm$ 75	3.7 $\pm$ 0.8	3.4 $\pm$ 0.7

Table 4. Structural characteristics of *Pinus pinea* plantations and biomass classes. Means of plant density, plant height, and total basal area  $\pm$  standard deviations are shown.

Biomass classes tons ha <sup>-1</sup>	Plant density plant ha <sup>-1</sup>	Height m	Total basal area m <sup>2</sup> ha <sup>-1</sup>
6–30	1600 $\pm$ 250	1.9 $\pm$ 0.6	8.4 $\pm$ 0.06
31–60	66.9 $\pm$ 3.4	14.7 $\pm$ 0.5	9.0 $\pm$ 0.09
61–90	137.1 $\pm$ 16.3	12.8 $\pm$ 0.8	14.5 $\pm$ 0.05
91–120	186.1 $\pm$ 23.6	13.1 $\pm$ 1.3	20.6 $\pm$ 0.20
121–150	150.0 $\pm$ 20.3	15.8 $\pm$ 0.3	23.4 $\pm$ 0.06
151–180	152.7 $\pm$ 25.2	19.5 $\pm$ 1.7	35.1 $\pm$ 1.10
181–210	85.4 $\pm$ 3.1	22.6 $\pm$ 0.3	26.1 $\pm$ 0.07
211–240	116.6 $\pm$ 16.2	21.6 $\pm$ 1.1	32.5 $\pm$ 0.06
241–270	153.3 $\pm$ 21.1	21.3 $\pm$ 1.6	41.9 $\pm$ 0.20
271–300	137.0 $\pm$ 2.2	22.4 $\pm$ 0.1	41.1 $\pm$ 0.03
301–330	188.4 $\pm$ 5.9	20.2 $\pm$ 1.5	46.4 $\pm$ 0.90

### Eucalyptus globulus Plantations

This was an example of a cultivated system; plant density was controlled and silvicultural practices were effectuated periodically. This species was recently introduced in the Estate. The average height ranged from 11.3  $\pm$  1.2 to 18.0  $\pm$  0.9 m (Tab. 6). According to plant density (range 1600–2800 plants ha<sup>-1</sup>) and plant diameter (range 9.4–20 cm) biomass classes varied from 31 to 240 tons ha<sup>-1</sup>. LAI ranged from 1.1 to 1.5.

### Grassland

Grassland was dominated by *Verbascum sinuatum* L., *Daucus carota* L., *Ranunculus bulbosus* L., *Dasyphyrum villosum* (L.) Borbás, *Avena barbata* Potter, *Dactylis glomerata* L., and *Asphodelus microcarpus*

Table 6. Structural characteristics of *Eucalyptus globulus* plantations and biomass classes. Means of plant density, plant height, and total basal area  $\pm$  standard deviations are shown.

Biomass classes tons ha <sup>-1</sup>	Plant density plant ha <sup>-1</sup>	Height m	Total basal area m <sup>2</sup> ha <sup>-1</sup>
31–60	2800 $\pm$ 112	11.3 $\pm$ 1.2	19.3 $\pm$ 2.1
61–90	2700 $\pm$ 97	13.0 $\pm$ 0.7	27.1 $\pm$ 1.6
91–120	1900 $\pm$ 56	15.0 $\pm$ 0.5	29.6 $\pm$ 1.2
121–150	1600 $\pm$ 45	18.0 $\pm$ 0.9	40.7 $\pm$ 1.7
181–210	1900 $\pm$ 73	17.0 $\pm$ 0.1	55.1 $\pm$ 2.1
211–240	2000 $\pm$ 127	16.0 $\pm$ 0.5	62.8 $\pm$ 1.5

Salzm. et Viv. The average plant height was 45  $\pm$  6 cm; total biomass ranged from 1.0 to 5.0 tons ha<sup>-1</sup> and LAI from 0.6 to 2.0 (Fig. 2, 3).

### Agricultural Areas

The crop productivity changed according to the cultivated species ranging from 2.4 tons ha<sup>-1</sup> (oats) to 4.0 tons ha<sup>-1</sup> (wheat).

### Regression Analysis

Plant above-ground biomass, height, and LAI were significantly correlated: the regression analysis of LAI versus height and biomass versus LAI (Fig. 4) were highly significant ( $r = 0.65$ ,  $P = 0.01$  and  $r = 0.87$ ,  $P = 0.01$ , respectively) (Fig. 4), emphasizing the interaction between the variables.

### DISCUSSION

Plant structure plays a fundamental role in a number of plant processes; it represents an important piece of

Table 5. Structural characteristics of broadleaf mixed forests and biomass classes. Means of plant density, plant height, and total basal area  $\pm$  standard deviations are shown.

Biomass classes tons ha <sup>-1</sup>		Plant density plant ha <sup>-1</sup>	Height m	Total basal area m <sup>2</sup> ha <sup>-1</sup>
91–120	Dominant layer	42.5 $\pm$ 7.5	14.7 $\pm$ 1.9	5.6 $\pm$ 0.7
	Dominated layer	11,051 $\pm$ 349	3.1 $\pm$ 0.8	5.5 $\pm$ 0.2
121–150	Dominant layer	54.0 $\pm$ 5.8	15.6 $\pm$ 1.9	11.3 $\pm$ 2.5
	Dominated layer	7886 $\pm$ 90	3.9 $\pm$ 0.7	15.2 $\pm$ 1.7
151–180	Dominant layer	49.4 $\pm$ 4.6	17.9 $\pm$ 0.4	15.1 $\pm$ 2.1
	Dominated layer	9270 $\pm$ 215	4.2 $\pm$ 1.1	17.8 $\pm$ 2.3
181–210	Dominant layer	37.5 $\pm$ 7.5	19.4 $\pm$ 0.9	18.6 $\pm$ 3.5
	Dominated layer	5863 $\pm$ 63	4.6 $\pm$ 1.5	15.6 $\pm$ 2.7
211–240	Dominant layer	66.7 $\pm$ 11.6	18.5 $\pm$ 1.0	25.5 $\pm$ 4.3
	Dominated layer	4680 $\pm$ 75	5.2 $\pm$ 1.2	10.4 $\pm$ 2.9
241–270	Dominant layer	70.0 $\pm$ 8.0	18.8 $\pm$ 0.5	28.8 $\pm$ 4.9
	Dominated layer	3200 $\pm$ 29	8.1 $\pm$ 0.9	10.8 $\pm$ 2.6
271–300	Dominant layer	52.4 $\pm$ 5.5	18.9 $\pm$ 1.4	23.1 $\pm$ 6.3
	Dominated layer	6850 $\pm$ 87	8.6 $\pm$ 0.9	28.6 $\pm$ 5.1
301–330	Dominant layer	88.0 $\pm$ 14	19.1 $\pm$ 0.7	38.2 $\pm$ 3.2
	Dominated layer	3863 $\pm$ 75	2.9 $\pm$ 0.8	2.6 $\pm$ 0.7
331–360	Dominant layer	50.0 $\pm$ 7.5	20.2 $\pm$ 0.3	30.6 $\pm$ 4.9
	Dominated layer	6150 $\pm$ 72	8.1 $\pm$ 0.9	27.2 $\pm$ 5.8

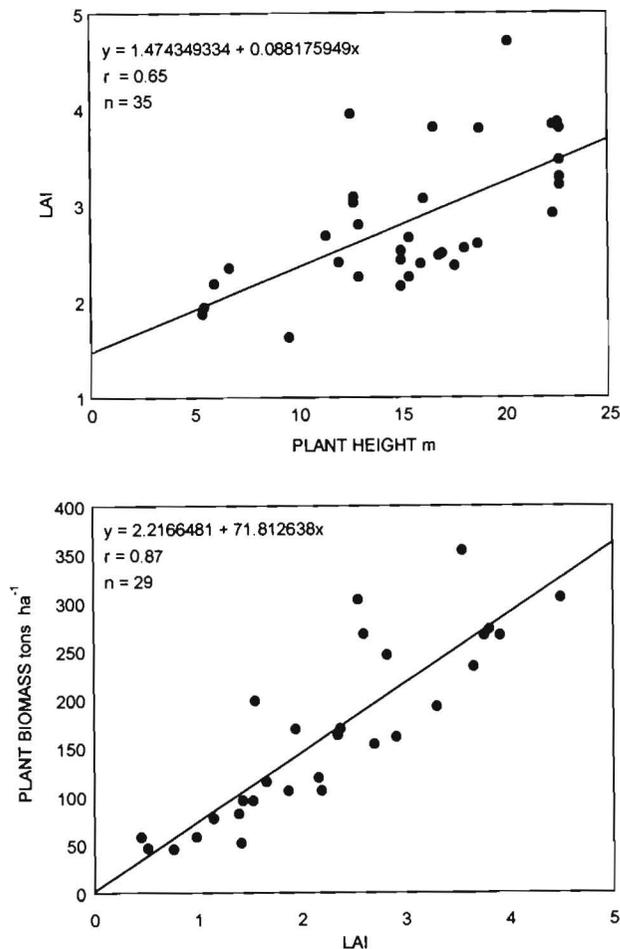


Fig. 4. Regression analyses of LAI versus height ( $P = 0.01$ ), above, and biomass versus LAI ( $P = 0.01$ ), below.

information for describing interactions between vegetation and its environment (Brenner et al. 1995). Plant biomass and structure result from the interactions of several variables acting on vegetation at different levels (Gratani and Amadori 1991; Gratani et al. 1999) and leaf area index, vertical and horizontal denseness are important structural parameters of vegetation (Barkman 1988).

Many predictions of future climate include an expectation that changes in average values of climatic variables may modify the intensity and the interaction of environmental stresses on plants (Naveh and Lieberman 1990); besides, considerable attention has been given to plant response to increased anthropogenic pressure (Oliveira et al. 1994). Consequently, properties of vegetation, including species composition, plant structure, plant biomass, and canopy profile may be used to realize ecosystem inventories giving information on the status and the impact of interactive multistress on natural resources.

Our results on the whole show that plant biomass, height, and LAI are significantly correlated. The "Plant Biomass Map" allows us to delimit: high bio-

mass systems (from 301  $\text{tons ha}^{-1}$  to 360  $\text{tons ha}^{-1}$ ), corresponding to the more mature *Pinus pinea* plantations, *Quercus ilex* evergreen forests, and broadleaf mixed forests; average biomass systems (from 61  $\text{tons ha}^{-1}$  to 90  $\text{tons ha}^{-1}$ ), corresponding to Mediterranean maquis, *Pinus pinea* plantations, (the youngest), *Eucalyptus globulus* plantations and *Quercus suber* evergreen forests; low biomass systems (lower than 5  $\text{tons ha}^{-1}$ ), corresponding to grassland and psammophilous vegetation. The "Leaf Area Index Map" shows the distribution of LAI classes in the district, in which the highest values identify the most stratified forested systems. Anthropogenic perturbation (fire, pasture, cutting, and reforestation) or natural disturbances may change forest structure, forest biomass, LAI, and probably forest type. Experiments designed to compare tree growth efficiency over a range of canopy leaf area provide means of assessing the relative importance of various factors upon productivity at a given reference point (Waring 1983). Shao et al. (1995) suggest that the decrease of forest LAI in response to climatic changes might be an important mean to survive in warmer and drier environments.

The results underline that changes in species biomass and species structure appear at ecosystem level: on the average plant biomass, plant height, and LAI rise according to increasing vegetation type complexity and the highest values are related to the stratified forested vegetation types. Stand density influences the distribution of leaf area index and plant growth (Gratani 1996; Gratani and Foti 1998). Few comparisons of methods for measuring leaf area index have been published for individual bushes and forests (Brenner et al. 1995); because direct estimation of LAI in forests is very laborious, the development of theory to rapidly estimate LAI has received a great deal of attention in recent years (Norman and Campbell 1989; Rich 1990; Gower and Norman 1991; Shao et al. 1995). Ford and Newbould (1971) studied a model to determine production of *Castanea sativa* forests by structural parameters, biomass, and LAI. Specht and Specht (1989) emphasized the relationship between LAI and the evaporative water flux through the canopy to describe plant production of *Eucalyptus*-dominated communities; total leaf area is, in fact, the most important factor influencing carbon assimilation and water loss in plant communities. Morales et al. (1996) analyzed relationships between height and leaf area, LAI and height, and height and leaf area density of Laurel forests in Tenerife (Canary Islands) emphasizing the importance of stand structure to forecast development and productivity trends. Parker et al. (1989) developed an indirect LAI measurement by litterfall observations in deciduous species. Shao et al. (1995) realized a model to assess climatic change effects on forest landscapes at a regional scale by using the following key words:

LAI, biomass, and tree height. Our results underline that ecosystem structure may be monitored long-time by means of the realized correlation between LAI and biomass. The identified biomass and LAI classes are important to establish the range of the existence of each of the communities; changes of physiognomy have been observed outside the range (classes). The long-term monitoring to verify if the biomass and LAI values are in the identified ranges may be easily achieved by LAI measurements, which can be converted into biomass values by their relationship. LAI is regarded as one of the most important characteristics of canopy structure (Morales et al. 1996) and estimation of LAI is a prerequisite for any productivity study (Assmann 1970; Ford 1982; Katsuno and Hozumi 1990; Oliver and Larson 1990). Waring (1985) and Gratani et al. (1994) suggest that LAI may also be a useful characteristic to monitor early symptoms of natural and anthropogenic stresses on forests.

#### CONCLUSIONS

The Maps realized in this study enable us to give quantitative information of natural, seminatural and cultivated resources of a large district in excellently preserved conditions, which require long-term monitoring programs aimed at determining community composition, structure, and biomass changing over time. Estate management decisions could be made more easily by these inventories of data which incorporate useful information on the status of ecosystems and trends. Biomass and LAI Maps could be employed as a computerised mapped information system for natural resource policy, regional planning, and landscape management. These data could be set up in a model and used to assess the potential effect of perturbation on this area, constituting a database of regional agencies for any management project. These inventories of land units provide a critical basis for: 1) further studies on ecosystem functioning; 2) the effects of adding or removing species from a system; 3) the identification of high biodiversity areas; and 4) the evaluation of threatened and priority areas for conservation. Based on such mapped information land-use decisions could easily be made because they incorporate all available information.

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