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Pianosa Island: Structure, Functioning and Biodiversity of Main Ecosystems

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Summary

Structure, ecophysiology and productivity of the main island ecosystems were studied. The studied ecosystems showed a different species composition, with different dominant plant species. All ecosystems showed a high plant species richness (between 21 to 30), with a higher proportion of perennials (60 %) and a lower percentage of annuals (40 %). Herbaceous plants (85-98 %) were dominant with respect to woody species. Woody plants are the 14 % of the total number of species found in macchia and woodland ecosystems. In each type of ecosystems plant communities were dominated by few species, as for example, *Avena barbata* in pasture/cultivated fields, or *Juniperus phoenicia* in macchia ecosystems. On pasture/cultivated fields a progressive invasion of pioneer shrub species is actually undergoing. Species association of macchia vegetation is very similar to so called "*Ginepreto Rupestre*", while some macchia areas showed a canopy height typical of *Meso-Mediterranean Macchia*. The pasture/cultivated fields and the macchia areas cover around the 53 and 37 % of island surface. On the other hand, a great fraction of island dry biomass was formed by macchia vegetation (61 %), while pasture/cultivated fields vegetation represent around the 26 % and woodlands only the 13 % of island biomass. In woodlands, species richness was associated to a higher Simpson index (0.502) with respect to macchia and pasture/cultivated fields. However the Shannon diversity index was found higher in macchia sites (0.415). Woodlands were also characterized by a higher diversity between families, as indicated by the Shannon index values, that were around 2.6, with respect to macchia (1,17) and pasture/cultivated fields (1.29). Carbon isotope composition ($\delta^{13}C$) on leaf dry matter was used to assess differences in photosynthetic carbon isotope discrimination (Δ) and water-use efficiency (WUE) of the dominant species colonizing the main island ecosystems. This analysis indicated lower Δ and, hence, higher WUE in macchia and woodland ecosystem species than those of abandoned agricultural fields. During the warm summer *Rosmarinus officinalis* showed the highest photosynthetic rates (around 10 μmol $m^{-2}s^{-1}$), within macchia vegetation. Carbon density for macchia vegetation was around 0.99 Kg of C m^{-2} , while nitrogen was 0.013 Kg of N m^{-2}. Data colleted suggested that a re-naturalization processes it is actually occurring on Pianosa island, particularly on pasture/cultivated fields. Plant communities within each type of ecosystem studied, showed a similar species composition. Therefore, Pianosa island represents an important spot for biodiversity conservation and carbon sequestration in the Mediterranean sea, however data collected are not exhaustive to know the entire functioning and structure of the island, but indicate that those species that are more abundant in the three ecosystems probably will be the driving forces of ecosystem responses to changing environmental conditions.

Introduction

Global change research requires not only knowledge of how individual species respond to climate change and land use change, but also understanding of the responses of whole systems to their multiple and interacting drivers (Schulze et al., 1999). In this context if research methodology in ecophysiology is well-established (Pearcy et al., 1989), on the other hand approaches to studying ecosystems as whole, and theory required to identify key parameters that drive the multiple interaction at the ecosystems level and its effects on CO_2 fluxes, are less developed (Schulze, 1995). Ecosystems are complex systems composed of organisms, the physical environment, and their interaction. Terrestrial and aquatic ecosystems occur at many scales, and most have been influenced by human activity in one way or another. Approaches to ecosystem studies include mechanistic (process-oriented), empirical, and model-based investigations that address composition (i.e., species present), structure (arrangement of species in space) and function (energy flow and nutrient cycling) of ecosystems (see Vazzana, 1998). Such studies cover an enormous range of scales, from molecules and micro organisms to entire landscapes. The ultimate goal of ecosystem research is to generate new knowledge from theory, experimentation, and simulation modelling about the nature of the complex biotic-abiotic interactions that lie at the heart of ecosystem functioning (see Walker et al., 1999). This type of research is particularly difficult in an isolated national park, as Pianosa Island; in fact in this case methodologies that could be use are limited and seasonal trends of measured parameters are difficult to obtain.

The aim of this part of the Pianosa_Lab project was to describe the structure, physiological ecology, productivity and carbon budget of the main vegetation systems found on the island.

Material and Methods

Ecosystems Types and Sampling Sites

With the aim to analyze plant communities of Pianosa Island, tree main types of ecosystems were considered: Abandoned pastures/cultivated fields, Macchia (i.e Mediterranean shrubland) and Woodlands. Measurements for the quantitative analysis of structure and species composition of the studied ecosystems types, were performed on a several number of sampling sites at Pianosa Island during spring an summer of 2001 and 2002. Site location was choose randomly, for each type of ecosystem 4-9 sites where used. For each sampling site measurements were performed along two transects of 100 m. Therefore along these, three sampling points were choose randomly.

Quantitative Measurements on Vegetation

Abandoned pasture lands and abandoned cultivated fields

On these ecosystems, canopy height was obtained, at each sampling point, by measuring plant height on 5 different plants. Total above ground dry biomass was determined by harvesting herbage on a area of 1 m^2 near the sampling point and then drying plant material for 48 hours at + 80 °C. Vegetation species composition and their relative abundance, was evaluated by applying the method of Braun-Blanquet (1952). The following relative abundance scale was adopted: 1) rare (species represented by less than 10 plants); 2) present (species represented by 10 plants or with a cover lower than 25 %); 3) 25-50 % abundance (species with a cover ranging from 25 to 50 %); 4) 50-75 % abundance (species with a cover ranging from 50 to 75 %); 5) > 75 % abundance (species with a cover higher of 75 %).

Vegetation soil cover was estimated by measuring on each sampling point, along sampling transects, vegetation reflectance using a Crop-Scan radiometer (CropScan Inc., USA). Measurements were repeat three times for each sampling points. The field of view of the instrument covered a area of approximately 1.2 m^2.

Macchia

On Macchia sites, species composition of vegetation and their relative abundance were performed according to Braun-Blanquet method (1952), as described above for pasture/cultivated fields. Above ground dry biomass of vegetation was estimated considering only shrubs species. At each sampling point, along transects, quantitative analysis of vegetation was performed using the point-centred quarter method (Cottan et al., 1953). Therefore, the following parameters were obtained: absolute plant density, absolute density of each individual species, relative frequency of each species and mean relative area covered by each species. Moreover, on each sampled plant also height and length of two main crows diameters were measured. For each species, total above ground dry biomass were estimated, according to Usò et al. (1997) as: $B_s = a + b\ V_a$, where a, b represent empirical parameters, V_a indicate the apparent volume of plants estimated as $V_a = (\square\ d^2 H)/4$; d and H indicate respectively mean crow diameter and plant height. Parameters a and b were estimated by non-linear regression (with a Statistica 5.0, Stasoft Inc., statistical package) using dry biomass and quantitative data measured on 5 plants for each representative species of macchia vegetation. Also the fraction of green biomass respect to total biomass was estimated.

Woodland

At each sampling point the point-centred quarter method (Cottan et al., 1953) was applied to estimate absolute tree density, absolute basal area, tree frequency, density and basal area of each constituent species of the canopy. On each sampled tree also plant height was measured (using a hypsometer). Therefore total timber volume of each species was obtained as: $V = D \times \sum(G \times H \times 0.75)$ (0,75 = constant form factor, see Porciani, 1994), where G and H indicate respectively tree basal area and height of each sampled tree, while D represent total tree density of each species. Using V values, total stand dry weight of trees per hectare, B (kg/ha), was estimated as $B = 976{,}62\ V + 1{,}75$. The above linear equation was obtained using data from alsometric tables described by Castellani (1999). As for the other sites species composition analysed using the Braun-Blanquet method (1952).

Vegetation diversity

Diversity and dominance of plant species within each type of vegetation, and sampling site, was evaluated using the Shannon (H) and Simpson (D_s) index (see Shannon and Weaver, 1963; Goldsmith et al., 1986), calculated as:

$$D_s = \sum_{i=1}^{i=s} \left(\frac{N_i}{N}\right)^2$$

$$H = -\sum_{i=1}^{i=s} \left(\frac{N_i}{N}\right) Log\left(\frac{N_i}{N}\right)$$

Where N_i indicate the value of a quantitative parameter in the i^{th} species collected (ex. number of individuals, dry biomass, etc…) and N indicate the sum of the quantitative parameter for all species. Moreover, also similarity between sites within each type of vegetation was evaluate using the Sorensen similarity index (Sorensen **,** 1948):

$$CC = \frac{200 N_{xy}}{N_x + N_y}$$

Where N_{xy} indicate the number of common species between two sites x and y, while N_x and N_y indicates the total number of species found in site x and y.

Photosynthetic Activity

Photosynthetic activity were monitored by a Licor 6400 Photosynthesis System (Licor Inc., USA), on the main plant species of Macchia vegetation. Photosynthesis measurements were made on four plants per species, under the same conditions of light (1000 μmol $m^{-2}s^{-1}$), temperature (25 °C), relative humidity (28-30 %) and CO_2 concentration (360 μmol mol^{-1}). Measurements were performed only in June 2001.

Carbon isotope composition

Plant material was collected during May 2003 in different experimental sites (abandoned pasture/cultivated fields, macchia and woodland ecosystems) for carbon isotope analysis. Leaf samples of different plant species was oven-dried at 80°C and then reduced to a fine powder before carbon isotope analysis. Carbon isotope composition of organic samples were determined using a stable isotope mass spectrometer (IRMS, Model SIRAII, VG Isotech, Middlewich, UK) as described by Brugnoli and Lauteri (1991). Carbon isotope composition was calculated according to Farquhar et al. (1989) as:

$$\delta^{13}C = (R_s/R_{std}) - 1$$

where R_s and R_{std} are the isotope ratio ($^{13}C/^{12}C$) of the samples and of the international standard Vienna Pee Dee Belemnite (VPDB) respectively.

Land Use

Land use of the island was obtained by analysis and elaboration of airborne photos of the island (source Regione Toscana Government, Italy, photos of year 1988 and 1998) using a Arcview 3.2 GIS software (ESRI Foundation, USA). Data obtained was corrected and adjusted with direct measurements on the field. The following classes of vegetation systems were adopted: woodlands, macchia, pasture/cultivated fields, pasture/cultivated fields with macchia, macchia with woodland.

Carbon and Nitrogen Content

Plant carbon and nitrogen content (% of DW) were analyzed on some of the main species of macchia vegetation. The analysis was performed on 4 plants per species, according to the Kjeldahl . Total organic C and N contents were measured by a flash combustion technique (1800 °C under O_2 flow), according to Hind (1993), using a Carlo Erba NA 1500 CNS Elemental Analyser.

Results

The three types of studied ecosystems showed a different richness of plant species (Tab. 1): in woodland areas a higher number of species was found (35), with respect to pasture/ cultivated fields (21) and macchia areas (29). In all ecosystems perennials species were dominant (60 %), respect to annuals: however, a higher percentage of annuals was found in pasture/ cultivated fields (Tab. 1). In all studied areas herbaceous species were dominant (85-98 %) respect to woody species (1.7-14.1 %), however these last, showed a higher abundance in macchia and woodlands sites (Tab. 1). The three herbaceous species *Bromus fasciculatus, Daucus carota* and *Lagurus ovatus* were the most frequently encountered in all sampled sites. Moreover, around 21 species were found in a fraction of sampling sites ranging between 30 and 80 % of cases, while a higher number of species (61) were observed only in few sites (Tab. 2).

Table 2. Number of species in function of their site frequency

Class of Site Frequency (%)	N° Of Species
80-100	3
50-80	12
30-50	31
10-30	61

On Pasture/cultivated field 59 different specie were found, however these areas were dominated only by 18 species that showed a site frequency higher or equal to 50 % (Tab. 3).

Table 3 Relative abundance of species of Pasture/cultivated fields ecosystem, weighted for site frequency. Species reported are those that showed a site frequency higher, or equal, to 50 %.

Species	Abundance
Avena Barbata ; Asphodelus Ramosus ; Lagurus Ovatus	25-50 %
Plantago lanceolata; Daucus Carota ; Convolvulus Arvensis; Scolymus hispanicus; Rostraria cristata; Crepis fetida; Convolvulus althaeoides; Bromus fasciculatus; Asphodelus Fistulosus; Scabiosa marittima	Present
Euphorbia pinea; Verbascum sinuatum; Dactylis glomerata; Thymelaea irsuta; Pallenis Spinosa	Rare

Avena barbata, Lagurus ovatus and *Asphodelus ramosus* were found in all sampled sites, it showed a higher abundance (25-50 %) with respect to other observed species. Macchia areas showed a higher number of dominant species respect to pasture/cultivated fields: 64 plants species was found, 30 species of these were observed in more than 50 % of sampled sites (Tab. 4). Macchia was dominated by *Juniperus Phoenicia* (50-75 %) with the presence, in some case, of *Rosmarinus officinale, Bromus fasciculatu* and *Pistacia lentiscus (25-50 %)*. Other common species of Mediterranean shrublands, were found with a lower abundance (Tab. 4).

Woodland areas was characterized, with respect to the other ecosystems, by a lower number of dominant species (Tab. 5). In this areas *Pinus halepensis* showed a abundance higher of 75 %, was dominant and cover approximately an area of 98 %. However, in these sites a total number of 57 species was observed (Tab. 5).

Table 1. Mean n° of species for each ecosystem, percentage of herbaceous and woody species, their relative abundance (Ab.) obtained from Braun-Blanquet analysis and percentage of annuals species with respect to the total number of species. Each value represent the mean ± dev. st. With different letters are indicate significant difference between means for p <0.05.

Ecosystem	N° of Species	Herbaceous		Woody		Annuals (%)
		%	Ab. %	%	Ab. %	
Macchia	29,3^{ab} ± 6,2	85.9^{b} ± 3,1	Rare	14.1^{a} ± 2,2	25-50	34^{b} ± 4,6
Pasture/cultivated fields	21,7^{b} ± 5,0	98.3^{a} ± 0,5	Rare	1.7^{b} ± 4,6	Rare	39^{a} ± 1,1
Woodlands	35,5^{a} ± 3,5	86.0^{b} ± 1,2	Rare	14.0^{a} ± 3,5	25-50	31^{b} ± 2,2

Table 4 Relative abundance of species of Macchia ecosystems weighted for site frequency. Species reported are those that showed a site frequency higher, or equal, to 50 %.

Species	Abundance
Juniperus phoenicea;	50-75 %
Rosmarinus Officinale; Bromus fasciculatus; Pistacia lentiscus	25-50 %
Dactylis glomerata; Asparagus Acutifolius; Cistus creticus; Cistus monspeliensis; Helichrysum litoreum; Smilax aspera; Asphodelus ramosus; Daucus carota; Prasium majus; Pinus halepensis	Present
Trifolium campestre; Rubia peregrina; Lagurus ovatus; Dorycnium hirsutum; Ammoides Pusilla Allium subhirsutum; Trifolium angustifolium; Centaurium tenuiflorum; Bellardia trixago; Rostraria cristata; Piptatherum miliaceum; Linum strictum; Teucrium flavum; Satureia greca; Petrorhagia saxifraga; Briza maxima	Rare

Table 5. Relative abundance of species of Woodland ecosystems weighted for site frequency. Species reported are those that showed a site frequency higher, or equal, to 50 %

Species	Abundance
Pinus halepensis	> 75 %
Bromus fasciculatus; Pistacia lentiscus; Rosmarinus officinale; Lagurus ovatus; Piptatherum miliaceum	25-50 %
Juniperus phoenicea; Cistus monspeliensis; Cynosurus Echinatus; Prasium majus; Asphodelus ramosus ;Brachypodium plukenetii	Present
Cistus creticus; Thymelaea Irsuta; Euphorbia pinea; Solanum nigrum; Olea europaea; Agave americana; Hordeum leporinum; Avena barbata; Rostraria cristata; Geranium rotundifolium; Ammoides pupilla; Daucus Carota; Thapsia gargarica; Teucrium flavum; Sideritis romana; Ballota nigra; Satureia greca; Plantago lanceolata; Bellardia trixago; Rubia peregrina; Lonicera implexa; Chrysanthemum Coronarium; Sonchus Oleraceus; Crepis fetida; Smilax Aspera; Allium sphaerocephalon; Allium subhirsutum; Dactylis Glomerata; Brachypodium distachyon; Trisetum Paniceum; Teucrium fruticans; Petrorhagia saxifraga; Dorycnium hirsutum; Scabiosa marittima; Asparagus acutifolius	Rare

In macchia ecosystems a higher fraction of species found, appertained to *Apiaceae* and *Fabaceae* botanical families, while *Astaraceae* was dominant in pasture/cultivated fields. Woodland areas were dominated by *Poaceae* and *Lamiaceae* (Fig.1). In all ecosystems a higher number of botanical families were represented only by one or two species (Fig. 1).

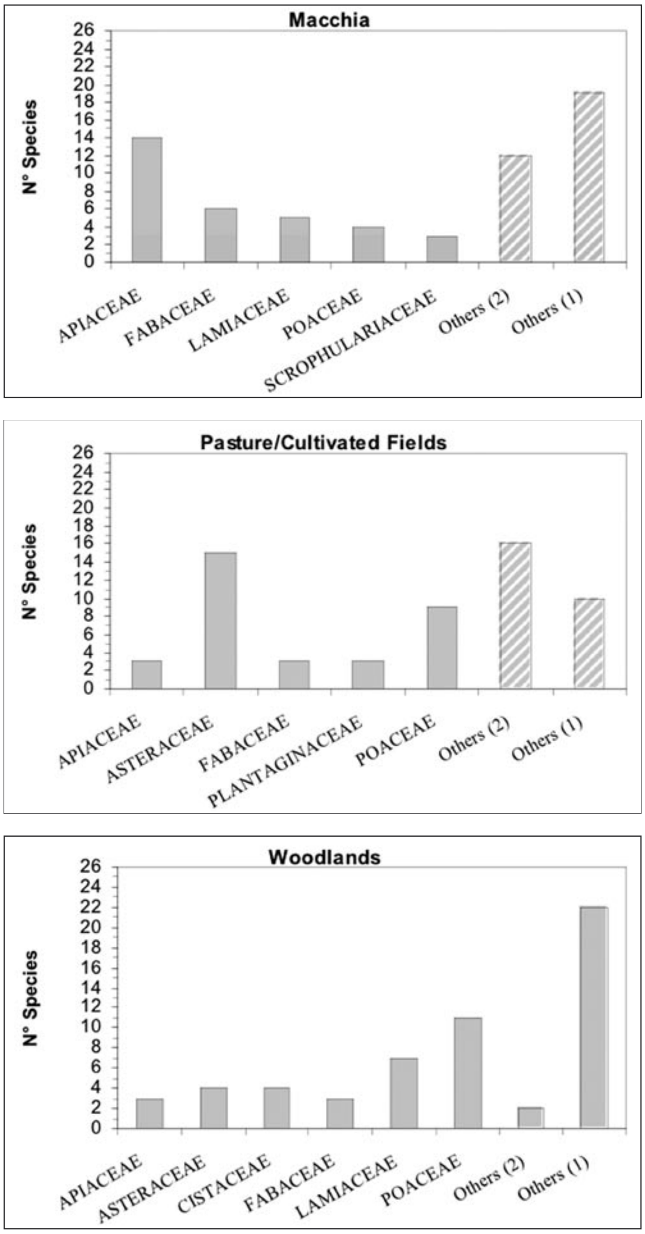

Fig. 1- Number of species for each botanical family in the three types of ecosystems. The groups others (1) and (2) are the sum of those families that were represented only by 1 or 2 species.

Table 6 Similarity between sites (CC), Simpson (D_s) and Shanon (H) index estimated for the three ecosystems. D_s and H were calculated both considering the total number of species and the number of species within each botanical family for each type of vegetation. With different letters are indicate significant difference between means (± dev.st.) for p <0.05 (Tukey HSD Test).

Ecosystem	Similarity (CC)	Simpson (D_s)		Shannon (H)	
		N° of Species	N° Species x Families	N° of Species	N° Species x Families
Macchia	87,45 [a] ±8,18	0,280 [b] ±0.02,	0,078 [b]±0.006	0.415 [a] ±0.04	1,29[b] ±0.001
Pasture/Cultivated Fields	97,19 [a] ±6,28	0.174 [c] ±0.012	0,107 [a] ±0.005	0.262 [c] ±0.014	1,17[c] ±0.002
Woodlands	73,23 [b] ±7,56	0,502[a] ±0.040	0,0818 [c]±0.003	0,300 [b] ±0.006	2,59[a] ±0.015

The Simpson index (D_s, Tab. 6), based on the total number of species found, were found higher (0.502) in woodlands with respect to macchia (0.28) and pasture/cultivated fields area (0.17, Tab.6). On the other hand the Shannon diversity index (H) were found higher in macchia sites (0.415) with respect to the other two ecosystems. When D_s and H were calculated considering the number of species per family within each type of ecosystem, it should be noticed that pasture/cultivated fields showed higher H values (0.107), while lower values were found in the other two ecosystems (Tab. 6). Woodlands were characterized by the higher diversity between families, as indicated by the H values, that were around 2.6, with respect to macchia (1,17) and pasture/cultivated fields (1.29, Tab. 6). Plant communities were very similar between the various sampling site of pasture/cultivated fields, as indicated by the higher values of the Sorensen similarity index (CC), while woodlands and macchia sites showed in same cases, a lower similarity between sites (Tab.6).

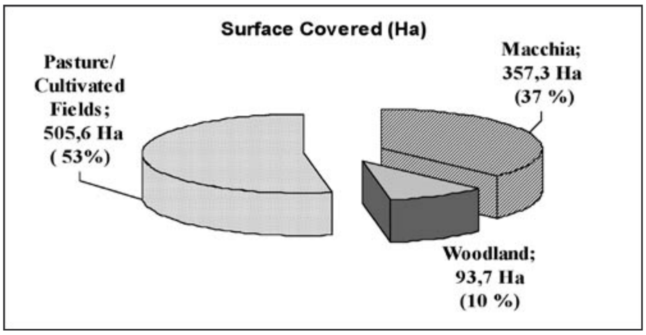

Fig. 2 Surface covered (Ha) by the three main ecosystems of Pianosa Islands.

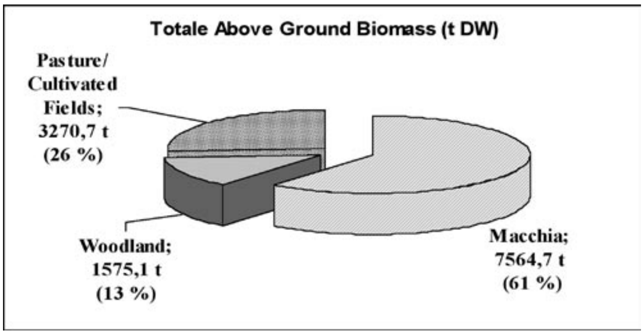

Fig. 3 Total above ground biomass dry weight (t of DW) of the main ecosystems of Pianosa Island.

Data colleted suggested that pasture/cultivated fields and the macchia ecosystems are those that cover the higher fraction of island surface, approximately the 53 and 37 % respectively (Fig. 2), while woodlands cover only the 10 %. As indicate in Fig. 3, total vegetation above ground biomass of the island were for a greater fraction formed by macchia vegetation (around 61 %) and pasture/cultivated fields (26 %), while lower fractions were related to woodlands (13 %) ecosystems.

The Simpson index (D_s), estimated on the basis of dry biomass per hectare (Tab. 7), were found higher in woodlands (around 0,8), with respect to macchia sites (0.5-0.3) and pasture/cultivated fields (0.3), consequently diversity, evaluated with the Shannon index (H) was found higher in these last two ecosystems. In fact, H ranging between 0.32-0.38 to 0.46-0.48 respectively in macchia and pasture/cultivated fields, while very low values was observed in woodlands (0.05-0.08).

Macchia ecosystems showed a higher plant density with respect to woodlands areas (Tab. 7), moreover in the first areas estimated leaf area index (LAI) ranging between 0.76 and 4.4, while in pasture/cultivated fields lower values were found (Tab. 7). The percentage of green above ground biomass, with respect to total, was found higher in macchia vegetation respect to pasture/cultivated fields ecosystems (Tab. 7). Mean vegetation height ranging between 6.9 to 15 m in woodland areas, while lower values were found in macchia (0.8-1.7 m) and pasture/cultivated fields (around 0.8 m, Tab. 7). Total biomass dry weight per hectare (Tab. 6) were higher in woodland areas, ranging between 14-37 t/ha, while lower ratios were found in macchia (9-32 t/ha) and pasture/cultivated fields (2.3-9.26 t/ha).

Most of pasture/cultivated fields and macchia areas showed a later successional stage respect to the others, therefore data colleted were also analyzed to take into account the following additional vegetation systems: macchia that will develop in woodland and pasture/cutivated fields that

Table 7 Mean canopy plant density, height, above ground biomass and leaf area index (LAI) for each type of ecosystem at Pianosa Island. On table are also report the Simpson (D_s) and the Shanon index (H) estimated on the basis of dry biomass of each sampled species. Data of 2001 and 2002 were related to differnt samples sites. With different letters are indicate significant difference between means (± dev.st.) for p <0.05 (Tukey HSD Test).

Ecosystem	Year	D_s	H	Density (plants Ha^{-1})	Height (m)	Biomass Dry Weight ($t\ Ha^{-1}$)	Biomass Dry Weight: Green	LAI
Macchia	2001	0.53^{b} ±0.20	0.32^{b} ±0.12	$2676{,}6^{ab}$ ±1844,65	1.8^{c} ±1.0	$9{,}45^{ab}$ ±5,04	35,42 %	$0{,}76^{b(2)}$ ±0,35
	2002	0.37^{b} ±0.12	0.38^{b} ±0.09	5721.13^{a} ±2317,74	0.82^{d} ±0.26	$32{,}64^{ab}$ ±22,59	33,21 %	$4{,}41^{a(2)}$ ±2,7
Pasture/Cultivated Fields	2001	0.35^{b} ±0.012	0.46^{a} ±0.008	-	0.82^{d} ±0.38	$9{,}26^{b}$ ±5,9	11,69 %	-
	2002	0.32^{b} ±0.096	0.44^{a} ±0.027	-	0.83^{d} ±0.33	$2{,}30^{c}$ ±0.75	13,3 %	$0{,}94^{b(1)}$ ±0.4
Woodlands	2001	$0{,}89^{a}$ ±0.09	$0{,}05^{c}$ ±0.006	361.8^{c} ±220.2	6.94^{b} ±1.2	14.80^{ab} ±6.27	-	-
	2002	0.82^{a} ±0.31	0.082^{c} ±0,14	605.4^{bc} ±263.2	12.08^{a} ±5.0	37.09^{a} ±16.51	-	-

(1)Estimated with crop scan measurements; (2)Estimated from quantitative analysis will develop in macchia vegetation. These two last systems corresponding to a area approximately of the 6,5 % of total island surface and corresponding to the 7,2 % of total above ground dry biomass (Tab. 8, Fig.4).

Forest of the island are dominated, for a great percentage, around 80 %, by trees with a trunk diameter and height lower than 30 cm and 10 m respectively. In Fig. 5 are indicate distibution between classes, of tree height and trunk

Table 8 Mean total above ground dry biomass (± dev. St.), surface covered, percentage of total biomass of total area covered by each ecosystem type. Data derived from the elaboration of Fig. 4. With different letters are indicate significant difference between means (± dev.st.) for p <0.05 (Tukey HSD Test).

Ecosystem Type	Area (Ha)	Total Biomass (t)	% Total Biomass	% Area
Macchia	339,7	7151,5± 5572,9 [a]	57,6	34,9
Woodlands	93,7	1575.1± 1477,1 [a]	12,7	9,6
Macchia -Woodlands	17,6	413,3 ± 282,8 [b]	3,3	1,8
Pasture/ Cultivated Fields -Macchia	45,3	607,9 ± 260,1 [b]	4.9	4,7
Pasture/ Cultivated Fields	460,3	2662,9 ± 2265,5[a]	21.5	48,9

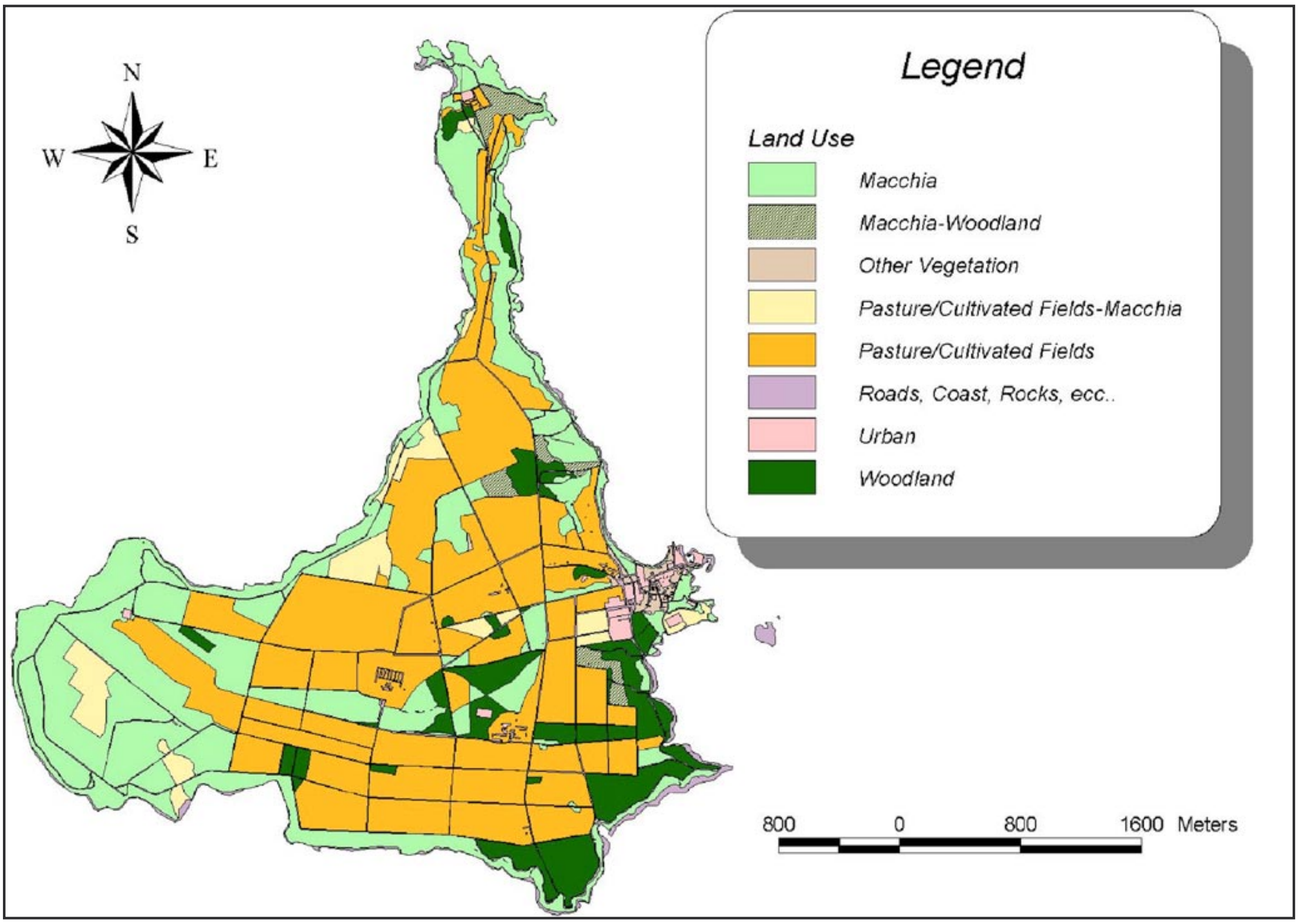

Fig.4 Land use of Pianosa Island.

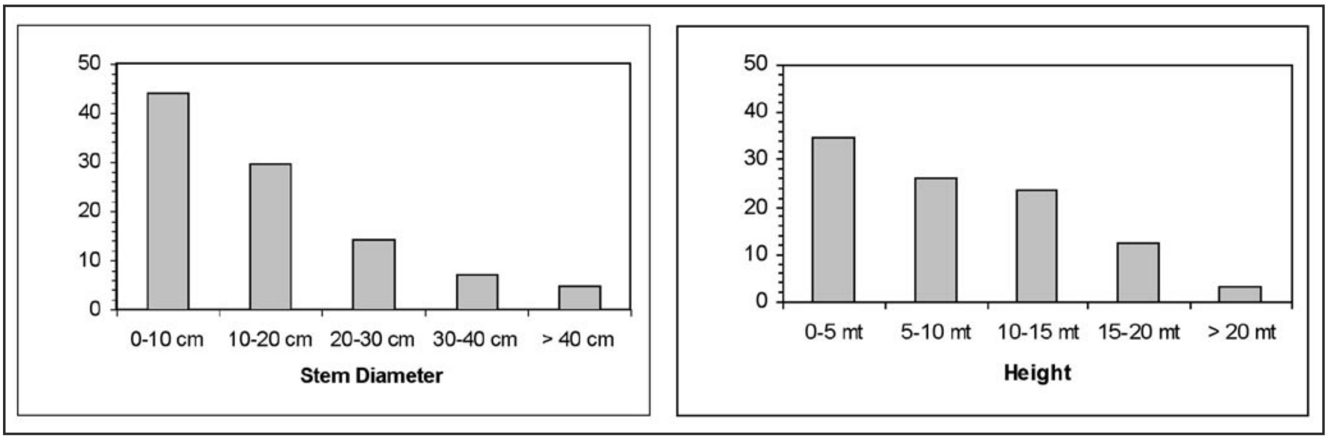

Fig.5 Distribution of trees between height (m) and trunk diameter (cm) classes in the Pianosa Islnad woodlands.

diameters (measured at 1,3 m): the distribution was similar to those of a pluri-stratified forest with trees that not have the same age (Fig.5).

Carbon Isotope Composition

Carbon isotope composition ($\delta^{13}C$) was determined on leaf dry matter of the dominant plant species collected in different ecosystems in Pianosa during spring 2003 (Table 9). The more frequent species of the macchia and the woodland ecosystems (see Table 4 and 5) showed higher leaf dry matter $\delta^{13}C$ values compared to those of abandoned agricultural fields (Table 3). Among plant species of Table 9, *Juniperus phoenicea* and *Pinus halepensis* showed the highest leaf $\delta^{13}C$ values.

Table 9. Carbon isotope composition measured on leaf dry matter of the dominant species collected in the Pianosa island ecosystems. Values are means ± SE (n=3).

Ecosystem	Plant species	leaf $\delta^{13}C$ (‰)
	Juniperus phoenicea	-23.9 ± 0.5
Macchia	*Pistacia lentiscus*	-26.0 ± 0.5
	Rosmarinus officinalis	-26.9 ± 0.1
	Avena barbata	-28.3 ± 0.1
Pasture/Cultivated field	*Asphodelus ramosus*	-28.1 ± 0.6
	Lagurus ovatus	-30.1 ± 0.1
Woodlands	*Pinus halepensis*	-24.4 ± 0.2

Photosynthetic Activity

Higher photosynthetic rates were found in *Rosmarinus officinalis* plants (around 10 μmol $m^{-2}s^{-1}$), with respect to the other studied species, on the other hand *P. halepensis* and *C. mospeliensis* showed the lowest photosynthetic activity (Fig. 6). Intermediary values of photosynthesis was found for the other studied species of macchia areas.

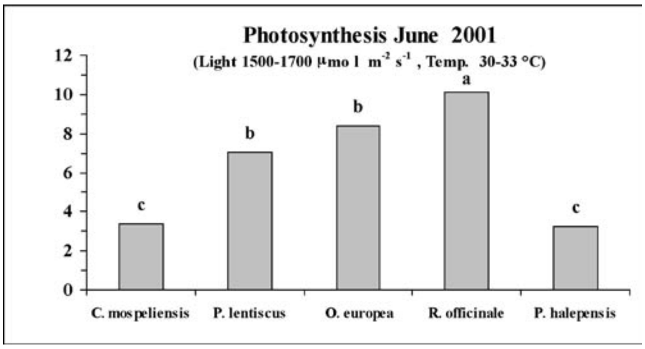

Fig.6 Photosynthetic rates (A_n) of some of the main Macchia species, measured under the same conditions in June 2001.

Carbon and Nitrogen Content

Carbon and nitrogen content (%) were analyzed on some of the main species of macchia vegetation. Mean carbon and nitrogen content of macchia plants ranged between 45.7 to 48.62 and 0.38 to 0.85 % respectively (Tab. 10). Moreover, mean C/N ratio were around 59.9 in green tissues and 138.3 in dead tissues (Tab. 10). Data colleted permit to estimate a mean carbon density for macchia vegetation around 0.99 Kg of C /m^2. Nitrogen density was around 0.013 kg of C /m^2 for the entire macchia areas of the island.

Discussion

The Macchia areas will have an important rule for future development of Pianosa island vegetation. Actually, this type of vegetation represent the 60 % of total island above ground biomass, while the remaining fraction is formed by the other types of vegetation. Macchia vegetation of studied island is well developed, as indicated by higher values of canopy height and plant density. This vegetation is dominated by a mixture of sclerophyllous trees, bushes and herbaceous typical of semiarid zones (Baldini, 2000). Moreover, macchia vegetation showed a higher number of rare species and a higher diversity. Along the coastal perimeter of the island it is also possible to identify the association *Crithmo-Limonietea* characterised by the presence of the endemic species *Limonium planesiae* (Baldini, 2000). It isn't possible to define a unique species association for Macchia plant communities: most of studied macchia areas showed a mean vegetation height typical of so called *Medium Meso-Mediterranean Macchia*, while in other areas canopy development was similar to so called *Tall Macchia*. In these last, species association was similar to *garriga* association described by Arrigoni (1998). The large diffusion in macchia vegetation of *Juniperus p.,* in conjunction with other shrubs (as *Cistus spp., Pistacia l.*), suggesting the presence of so called *Ginepreto Rupestre* association, a type of vegetation well adapted to growth under warm clime conditions (Arrigoni and Di Tommaso, 1981; Regione Toscana, 1998). All forested areas of the island derived from human activity, therefore woodlands are dominated by one species, *Pinus halepensis*. When the Shannon index was calculated on the basis of dry biomass this index assumed very low values for this type of vegetation. However, also if this areas cover only the 10 % of island surface it have an important ecological function for the following three reasons: 1) permit the development of a higher biodiversity; 2) have an important rule to determine most favourable micro-clime and environmental

Table 10 Carbon, Nitrogen Content (% of DW) and C/N ratio of some of the main species found in macchia areas. Each value represent the mean ± st.dev. With different letters are indicate significant differences between means (± dev. st.) for $p < 0.05$ (Tukey HSD test), while with a * are indicate significant differences between general means.

Element		*Cistus m.*	*Juniperus p.*	*Pistacia l.*	*Rosmarinus o.*	Mean
Carbon (%)	**Green**	47.98 [a] ±0.29	48.85 [a] ±0.99	47,99 [a] ±0.44	49,67 [a] ±0.84	48.62*±0.94
	Dead	44.57 [a] ±0.24	46.38 [a] ±0.53	45,24 [a] ±0.81	46,42 [a] ±0.24	45.65*±0.93
Nitrogen (%)	**Green**	1.0 [a] ±0.11	0.66 [b] ±0.10	0.95 [a] ±0.075	0.80 [ab] ±0.20	0.85 * ±0.17
	Dead	0.31 [b] ±0.08	0.27 [b] ±0.12	0.55 [a] ±0.09	0.38 [b] ±0.039	0.3 8*±0.13
C/N	**Green**	48.18 [b] ±5.31	74.79 [a] ±13.39	50.80 [b] ±3.68	65.70 [ab] ±20.05	59.87±15.58
	Dead	149.78 [a] ±41.64	196.05 [a] ±72.5	83.20 [a] ±14.67	124.0 [a] ±13.15	138.26±56.3

conditions for plant and animal species and 3) influence CO_2 fluxes between atmosphere and vegetation of the island.

Plant communities of pasture/cultivated fields were dominated by few species. In this areas with a higher frequency, was found *Avena barbata*, a invasive weed, that were commonly found in dry and calcareous soils (USDA, 2001): in conjunction with other species, it's a typical species of disturbed lands and grasslands. Moreover, in this areas a progressive re-naturalization processes of vegetation is actually occurring, as indicated by the presence of some typical macchia pioneer species (for ex. *Cistus mospeliensis*). On the other hand it is possible that these ecosystems affect island carbon fluxes, especially in those months of ther year when clime conditions are most favourable for herbaceous photosynthetic activity.

Biodiversity and landscape diversity of the island were deep modified by the past human activities, that introduced on the island some exotic species (as *Eucaliptus spp*.) and other invasive herbaceous species, that if will find and increasing diffusion in future, could lead whole water balance of the island, natural biodiversity and stability of island ecosystems (see Walker et al. 1999). However, the island territory is higher fragmented by structures and buildings (streets, stone walls, etc…), this fact could decline persistence of endemic species in the past, and resulting in a increasing invasion of exotic species (Hobbs, 1989). To the other hand plant species richness found on the island was higher if compared to other anthropogenic systems (Sala et al., 1999). However, the Simpson and Shannon index suggested that especially woodlands, are dominated by few species, in term of biomass, with a consequently reduction of diversity, but the diversity estimated by the Shannon index, based on the number of species per botanical families, appeared higher. It should be noticed that the plant communities were similar in the three types of studied ecosystems, as indicated by the higher values of the Sorensen similarity index. However, pasture/cultivated fields, if compared within each of them, showed a more similar species composition with respect to woodland and macchia areas.

Data collected suggested that in the three ecosystems vegetation evolution will be drive by those species that actually showed a higher abundance and a higher site frequency, as for example *Juniperus p.* in macchia ecosystems (see Sala et al., 1999). Species richness and ecosystems functioning showed a saturating relationship, depending on the taxonomic, and region considered (Vitousek and Hooper, 1993; Ricklefs, 1995; Tilman et al., 1996). Moreover, ecosystem processes are saturated by a relative lower number of species (Sala et al., 1999). Therefore, the higher number of species found on Pianosa Island is an important factor for ecosystem stability, for two reasons: 1) a higher number of species increase the probability of there being at least on species present and that is productive under a particular set of conditions; 2) additional species may be able to trap resources that are not captured by other species, due to differences in rooting depth, phenology, nitrogen required, etc… (Tilman, 1988; Chapin et al., 1997). Moreover, species richness may buffer ecosystem processes against extreme clime events (Tilman and Downing, 1994), or unanticipated effects of global change (McNaughton, 1993). Land diversity, plant community diversity, ecosystem diversity and species diversity within ecosystem, might confering stability to whole ecosystems processes (Chapin and Shaver, 1985).

Macchia ecosystems and woodlands of the island are dominated by sclerophyllous species, which are adapted well for surviving the summer drought, or to extreme drought conditions (see Osborne et al., 2000). Therefore, this vegetation probably play a key rule in determining primary productivity, carbon balance and structure of whole island ecosystems, as indicated by the higher summer photosynthetic ratios of some of the studied shrub species, and by the higher fraction of biomass, carbon and nitrogen allocated in this vegetation systems. However, carbon density of macchia vegetation appeared variable between the various sampling areas, and generally were lower respect to mean values, around 2 kg m^{-2}, reported by other authors for macchia vegetation (see Olsone et al, 1985).

Carbon isotope composition ($\delta^{13}C$) of leaf material is dependent on photosynthetic carbon isotope discrimination (Δ, Farquhar et al., 1989). Δ is linearly dependent on the ratio of intercellular and atmospheric partial pressures of CO_2 (p_i/p_a) and, hence, it is inversely related to water-use efficiency in C3 plants (WUE, Farquhar et al., 1989; Brugnoli and Farquhar, 2000). Table 9 shows leaf $\delta^{13}C$ values of the dominant species. These results indicate lower Δ and, hence, higher WUE, in the dominant macchia and woodland ecosystem species compared to dominant species colonising the abandoned agricultural fields. These results are interesting, and indicate a variation of ecosystem WUE with land-use change in a typical coastal Mediterranean environment. Among plant species of the Macchia, *Juniperus phoenicea* (the dominant species of this ecosystem, Table 4) was characterised by the highest $\delta^{13}C$ values. These results seem to indicate a high adaptation of this species to dry environment, showing low Δ and high WUE.

It is well accepted that temperature in the Mediterranean region has deviated somewhat from the global picture (Metaxas et al., 1991; Jones et al., 1998), but has shown an overall warning trend (Kutiel and Matheras, 1998). Moreover, as indicated by the PSDI index (see introduction chapter), extremely drought conditions events, increased in the last years at Pianosa island. Therefore, in future, both primary productivity and canopy structure could be limited by reduced supplies of water, vegetation could be subject to increases in the duration and severity of drought, with a consequently natural selection of those plant species that will be naturally selected to growth under the new abiotic conditions. In conclusion, Pianosa island represent an important spot for biodiversity conservation and carbon sequestration in the Mediterranean sea, data collected are not exaustive to know the entire functioning and structure of the island, but indicate that those species that are higher abundant in the three ecosystems probably will be the driving forces of ecosystems responses to changing environment conditions.

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