The Pianosa_LAB: An integrated research project to assess the carbon balance of Pianosa island

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Abstract

Major efforts have been made over the last decade to investigate and quantify gas exchange between the terrestrial biosphere and the atmosphere. Such exchange is, in fact, of special relevance as it is known to exert a major control on the global carbon (C) cycle. The Pianosa_LAB is a research project started in the 2000 in collaboration with the National Research Council, several Universities and the authorities of the National Tuscan Archipelago Park, to understand and quantify the C cycle in a confined ecosystem such as that of the island of Pianosa, by conventional and innovative research approaches. The island of Pianosa is especially suited for this type of investigation due to its special topography. The island is completely flat emerging only approximately of 15 m out of the sea surface. In addition, there are no anthropogenic sources of greenhouse gases on the island that may interfere with the proposed measurements, that provide useful information to quantify interactions and feedbacks between climate and local terrestrial ecosystem. The island of Pianosa is an excellent good analogue for a typical Mediterranean ecosystem where the natural vegetation is currently colonising the abandoned agricultural land and undergoing a process of re-naturalization. Furthermore, the Pianosa_LAB is attempting to integrate other activities, beside C cycle research, within the local context of a protected area thus creating synergies between science, environmental protection and the society. Here we present the main characteristic in terms of climate, geology, soil, vegetation and land-use of the island as well as its history, and describe the structure and objectives of the Pianosa_LAB project.

Introduction

The understanding and quantification of gas exchanges among biosphere and atmosphere is a priority of current global change research: plans for the reduction of anthropogenic emissions require verifiable information on regional sources of carbon (C) and uptakes in terrestrial ecosystems, in view of the Kyoto Protocol. Terrestrial ecosystems exchange annually 120 Pg of C with the atmosphere through natural processes, such as photosynthesis and respiration (Schlesinger, 1997). Anthropogenic activities have altered this balance with an annual emission of 6.3 ± 0.6 Pg C y^{-1} via fossil fuel burning, and of 1.6 ± 0.8 Pg C y^{-1} via land use change (IPCC, 2001). The anthropogenic C input to the atmosphere resulted in an annual increase of atmospheric carbon dioxide (CO_2) of 3.3 ± 0.2 Pg.C y^{-1}. This increment is only about 40% of anthropogenic emissions with the rest being reabsorbed partially by the ocean (2.3 ± 0.8 Pg C y^{-1}) and partially by the terrestrial biosphere (3.0 ± 2.3 Pg C y^{-1}). It is on the capacity of the biosphere and in particular the soil and wood components, to function as a C sink that rely most of the possibility to mitigate atmospheric CO_2 increment in the future. Through the management of terrestrial ecosystem human activities can partially control this sink activity. On the other hand, the global C balance is a driver of climate change as well as climate controls the natural rates of C fluxes.

The study of biosphere and atmosphere gas exchanges is the objective of a number of initiative at the national and international level (Valentini *et al*., 2000) but only a few specifically focussed on Mediterrranean ecosystems (Reichstein *et al*., 2000), despite the socio-economical as well as natural interest that these systems have worldwide and their sensitivity to climate change.

Mediterranean type ecosystems are found in five areas of the world: North America, Mediterranean Basin, Chile, Australia, and South Africa. They are complex socio-economical and biogeographycal systems where the global change driving forces are interacting with national policies and economic factors. The Mediterranean region is represented by a mosaic of landscapes, constituted by strongly dynamical patches of vegetation, where the balance between C uptake or release is highly dependent on disturbances and human management. Moreover, Mediterranean ecosystems are expected to be strongly affected by future climate change, and increasing land use pressures. In particular, the Intergovernmental Panel on Climate Change Report (IPCC, 2001) concluded that in this region "hot summers will double in frequency by the year 2020" resulting in decreased water availability and soil moisture and thus "desertification and forest fires will increase", with possible increases in precipitation will occur in winter.

The Pianosa_LAB is an unprecedented and innovative project aimed at the long-term monitoring of the actual exchange of greenhouse gases among the biosphere and the atmosphere in a Mediterranean ecosystem, thanks to an instrumented field network for long-term atmospheric monitoring that has been created on the Island of Pianosa.

The Pianosa island is especially suited for this type of investigation because of its very special topography and because of the complete absence of anthropogenic sources of greenhouse gases. Both those conditions are in fact creating a unique opportunity to measure total gas exchange, over a wide and heterogeneous area in a typical Mediterranean ecosystem.

The Pianosa island

Geography

The Pianosa island (Long. 10°04'44"E and Lat. 42°35'07"N) is the fifth, by extension, of the seven islands of the Tuscan Archipelago National Park, with a surface area of 10,2 km^2 and a coastal perimeter of approx. 20 km (De Giuli, 1970). The island "*Planasia"*, must its name to the completely flat morphology, with some small undulations, the highest elevation on the sea level is about 29 m, while the average altitude is about 18 m. A Digital Elevation Model (DEM) is show in Figure 1.

Climate

The climate of Pianosa differs from that of the other islands of the Tuscan Archipelago, due to its flat morphology. In fact, the flat shape does not offer to the humid air masses the possibility to condense and the rainfall are considerably lesser than those occurring in the other islands. Moreover due to the great permeability of the Pianosa soils, the rain is quickly drained and no surface waters are found on the island.

As part of the Pianosa_LAB activities, a satellite meteorological station was installed on the island from May 2000 (Zaldei *et al*., 2000). To complete climatologic analysis an historical meteorological series from 1951 to 2002 (collected by the Institute of Biometeorology CNR) was obtained merging, real collected data and interpolated data from meteorological stations located in the near Elba island.

Based on this historical meteorological series the Palmer Drought Severity Index (PDSI) (Palmer, 1965) was determined. This index is widely used as an indicator of regional drou-

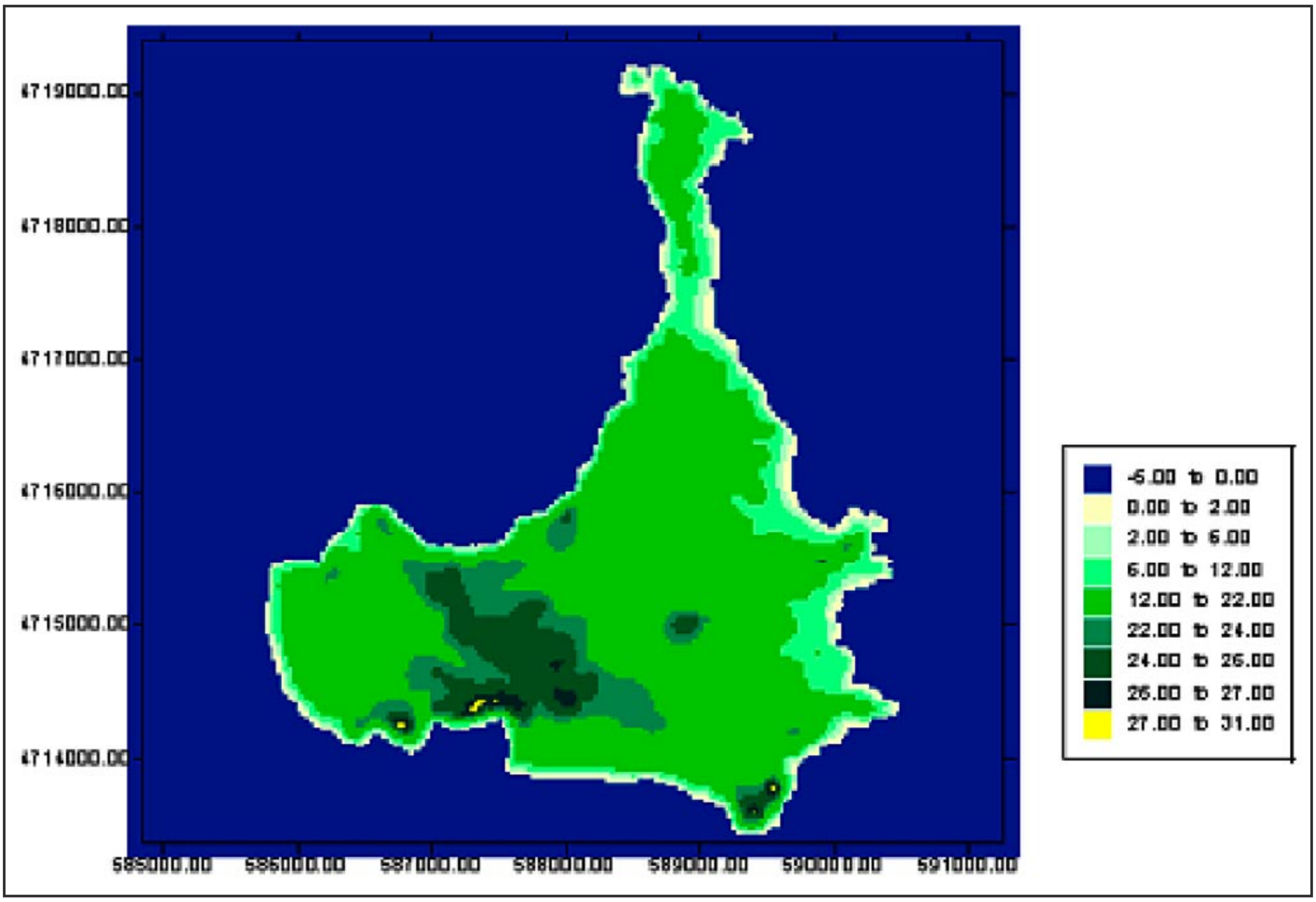

Figure 1 – Digital Elevation Model of Pianosa island.

ght conditions (Karl and Koscielny, 1982; Diaz, 1983; Szinell *et al*., 1998) and recently it had also been used in Climate Change Assessment (e.g. Central Great Plains Assessment, 1999). The PDSI combined the effects of temperature and precipitation, in particular measures the accumulated effect of monthly rainfall deficit/surplus relative to the monthly 'climatologically appropriate rainfall', defined as rainfall needed to maintain adequate soil water content for normal growth of plants in a region. This appropriate rainfall is a function of time and its monthly values are calculated from surface and soil water balance among evaporation, plant transpiration, runoff and available soil water for evaporation and transpiration (Palmer, 1965; Hu and Willson, 2000). The appropriate rainfall is a function of air temperature, through the evaporation and transpiration. In Table 1 it is reported the classification of the PDSI, concerning the dry periods and wet periods, while in Figure 2 it is reported the PDSI of the Pianosa calculated on yearly basis.

Table 1: PDSI classification

PDSI	Classification
4.00 or more	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to –0.49	Near normal
-0.50 to –0.99	Incipient dry spell
-1.00 to –1.99	Mild drought
-2.00 to –2.99	Moderate drought
-3.00 to –3.99	Severe drought
-4.00 or less	Extremely drought

Mean air temperature over the period 1951 – 2002 was 16,1 °C with a maximum of 21,7 °C while minimum air temperature was 10,4 °C. In figure 3 the average maximum and minimum air temperature over the period 1951-2002 are reported.

The general yearly pattern of precipitation shows maximum rainfall occurring from October to December followed by a drop down which reaches a minimum value in July. In Figure 4 the total yearly rainfall (mm) are reported from 1951 to 2002, which ranged between a minimum of 199 mm (1965) and a maximum of 726 mm (1983).

In Pianosa island the prevalent winds come either from the South or from the North with a respectively percentage values of 18,6 % and 16 %. The South-west wind (Libeccio) reaches the highest speed (up to 11.4 m s^{-1}), but occurs less frequently (5,4 %). The South winds are the most representative during the year, with maximum frequencies in June.

Geology and Soils

Pianosa Island is formed almost entirely on organogenetic limestone and Pliocene sandstone that overlie, at a depth of about 30 m, a complex of marly sediments dating back to Miocene. Quaternary eolian deposits, thick about 2 m and constituted of cemented yellow sand, marginally on the East Coast are present.

Above the Pliocene formation, there are Pleistocene deposits of different composition, such as whiten calcareous sandstone rich of gastropods and bivalves and red and yellow gravelly, sandy and silt materials come from the mainland.

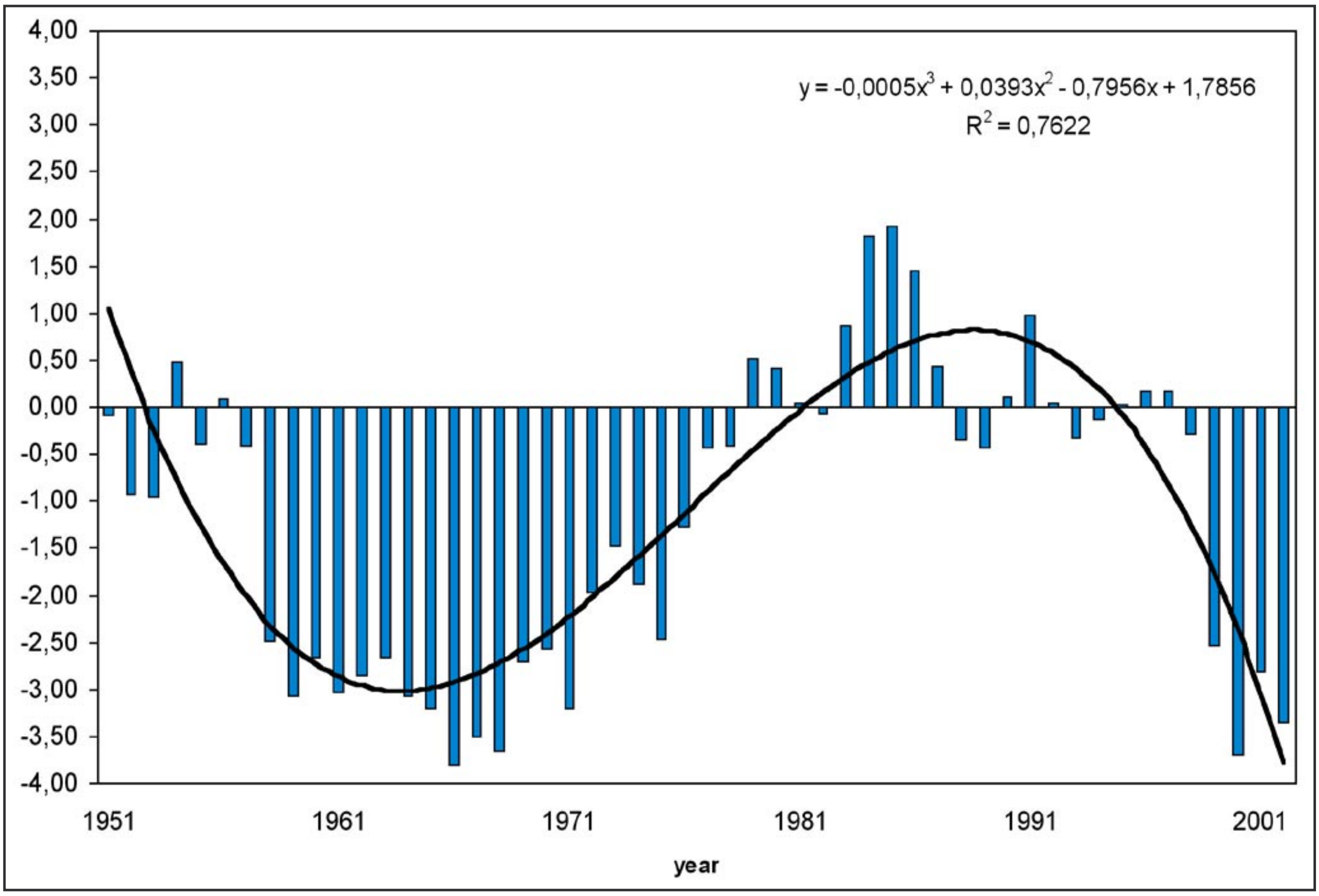

Figure 2 – PDSI determinated on yearly basis

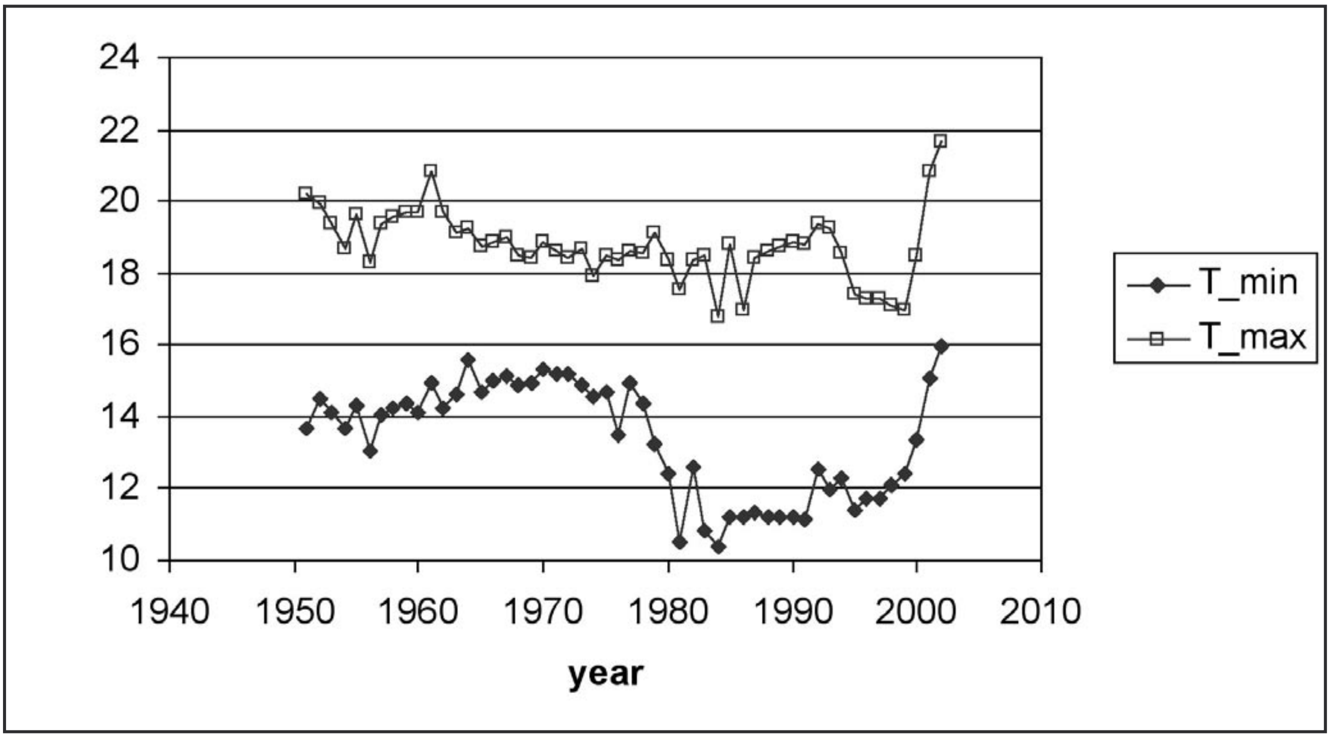

Figure 3 – Maximum and minimum air temperature of Pianosa island between 1951 and 2002.

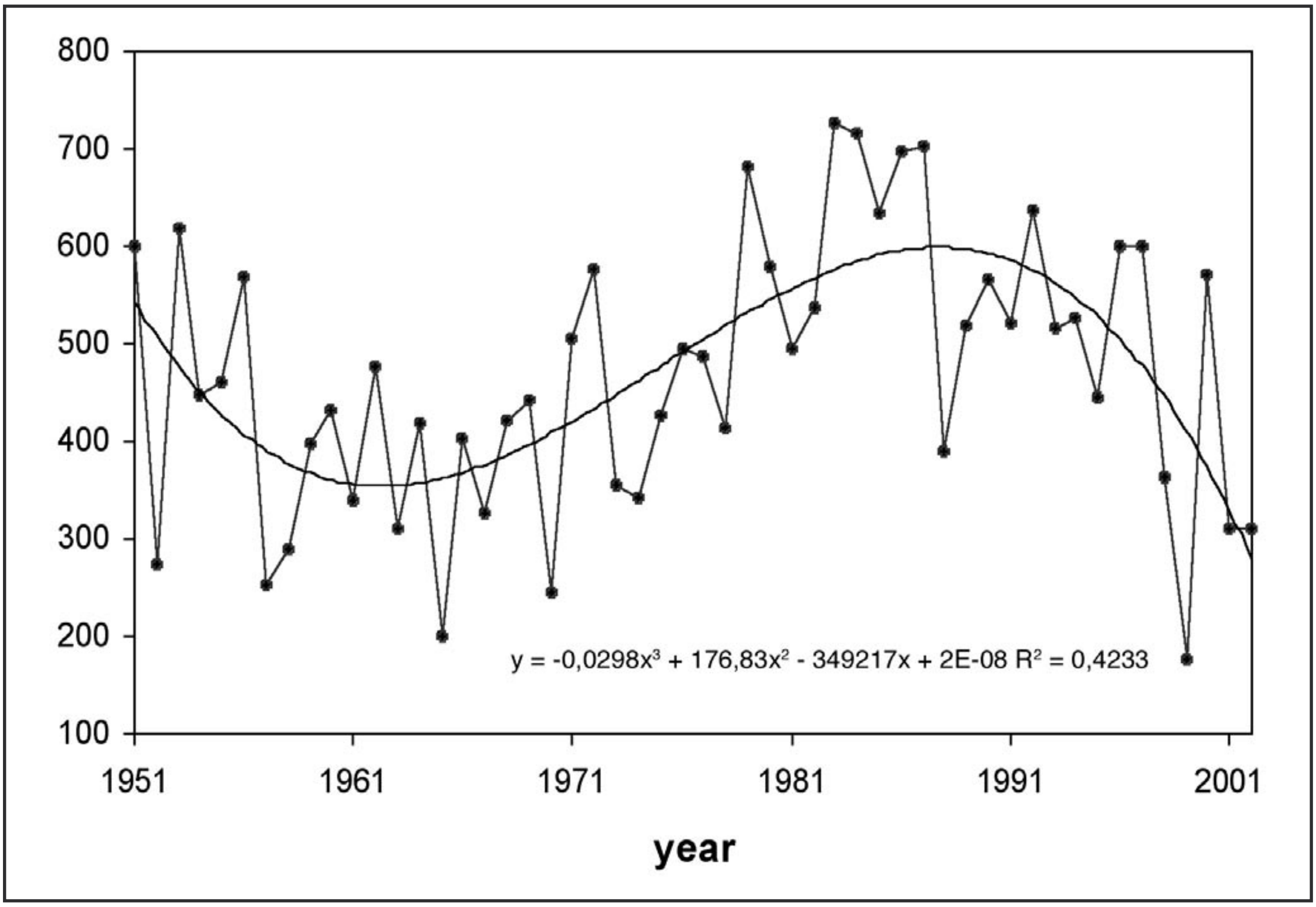

Figure 4 – Total year rainfall of Pianosa island between 1951 and 2002.

The soils of the island, developed with the contribution of marine and continental sediments (Bossio *et al*., 2000), are thin and mainly classifiable as Leptosols according to the World Reference Base for Soil Resources (ISSS-ISRIC-FAO, 1998). In any case, the soils are alkaline, rich of carbonates, loamy sand or sand and with a moderate content of rock fragments. The content of organic carbon is variable, strictly dependent on types of vegetation and management (Santi *et al*., this issue).

Vegetation

The original vegetation of Pianosa island was presumably represented by a Mediterranean macchia, dominated by a mixture of sclerophyllous and deciduous trees, bushes and grassland. This vegetation was strongly affected by the Penal Colony agriculture activities and today survives mainly along the coastal perimeter. In fact, it is only in the coastal perimeter that it is possible to identify the association *Crithmo-Limonietea* characterised by the presence of endemic species like, *Limonium planesiae* (Baldini, 2000).

The Mediterranean woodland found on the island is typical of calcareous soil dominated by the presence of *Rosmarinus officinalis*, *Cistus spp*. and *Juniperus phoenicia* (Baldini, 2000). Patches of this plant community exist at different evolution stages as a consequence of the progressive renaturalization process that the island is currently undergoing. Additionally small planted woods, characterised by the presence of *Pinus halepensis*, *Quercus ilex* and *Arbutus unedo,* are well represented, also few *Eucalyptus* trees planted along the edges of road paths, were encountered.

The highest fraction of the island's surface is represented by abandoned pasture and cultivated fields (Fig. 5) now covered by a species association typical of degraded Mediterranean agriculture soil dominated by: *Bromus fasciculatus, Daucus carota, Lagurus ovatus, Asphodelus ramosus, Avena barbata, Dactylis glomerata, Plantago lanceolata, Rostraria cristata, Asparagus acutifolius, Petrorhagia saxifraga* and *Scabiosa maritima*. A complete floristic analysis of the Pianosa island is reported by Baldini (2000) who identify more than 500 plant species.

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, abandoned arable fields, abandoned arable fields with macchia, macchia with woodland (Fig. 6).

History

The first historical record of Pianosa island dates back to the Roman age, when the Emperor Ottaviano, in the 6-7 A.C., forced the grandson Agrippa Postumo to live on Pianosa island. Following the decadence of the Roman Empire, during the periods of Barbarians' invasions, the island was abandoned (Chierici, 1995).

The name of Pianosa island newly appeared in some documents of the *Repubbliche Marinare* of Pisa and Genova (XII and XIII Century) that reported the remarkable strategic position of the island.

The 27th August 1802, Napoleone Bonaparte established that the islands of Elba, Capraia, Pianosa, Palmaiola and Montecristo were united to the territory of the French Republic. Bonaparte visited Pianosa twice and found it the most interesting of the other islands, appreciating its richness of vegetation and animals. During the Conference of Vienna (1815), all islands of the Tuscan archipelagos were annexed to the Kingdom of "Granducato of Tuscany" (Monti, 1988).

In 1858 Pianosa became an Agriculture Penal Colony, where the prisoners were forced to work in the fields (La Provincia di Livorno, 1962) During the '70s the jail of Pianosa became a maximum security penitentiary. Only in the '80s, representatives of the Government and members of the civil society started to propose to close the prison and to return Pianosa to the competent civil authority. In view

Figure 5 – Normalized Difference Vegetation Index (NDVI) of Pianosa in 1984 and 1994, showing a decrease in overall vegetation index associated to human activities. The dark and pale green areas represented the Mediterranean ecosystems, while the red and brown areas represented tilled and pasture areas. White areas are buildings and roads.

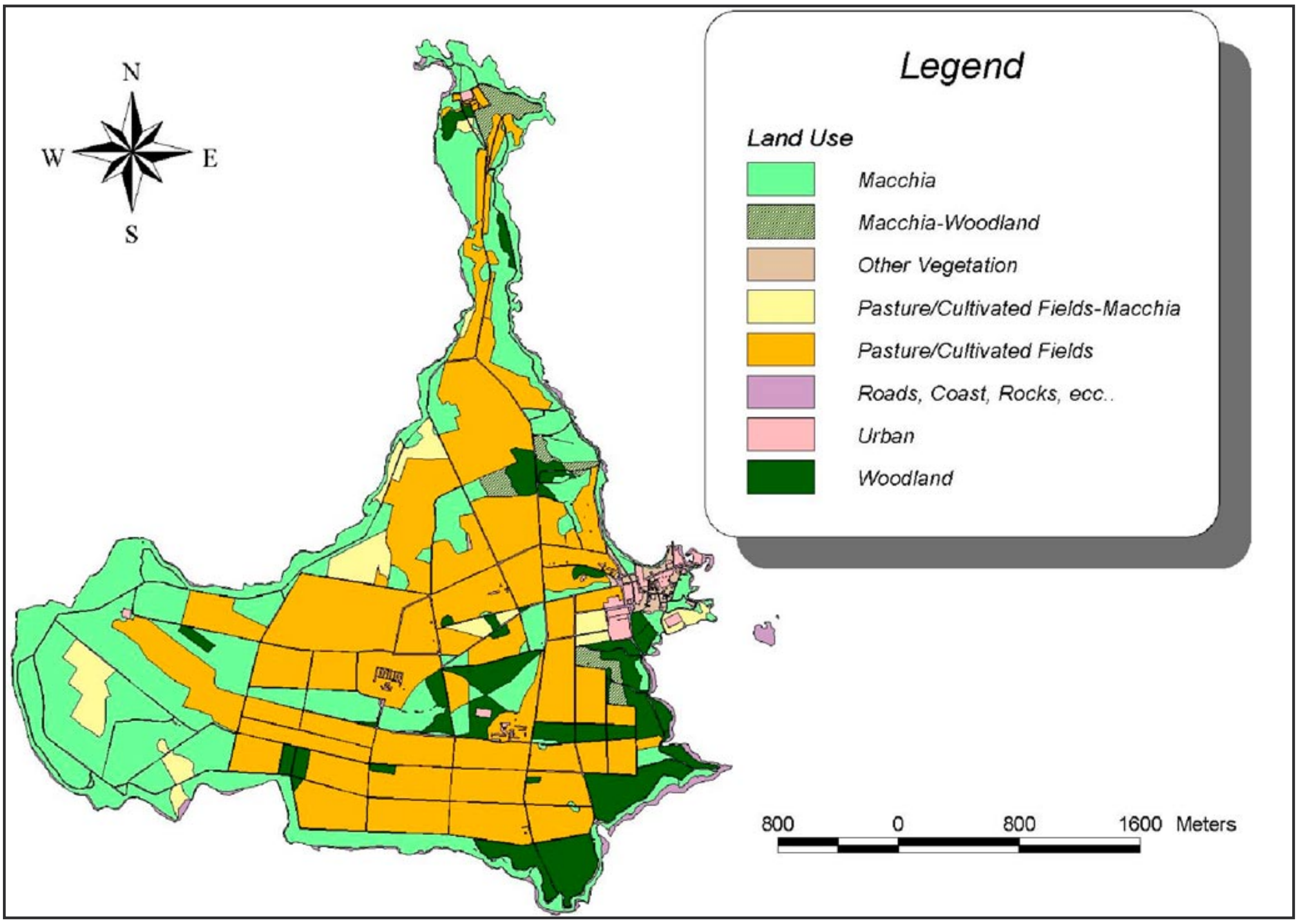

Figure 6 - Land use of Pianosa Island

of this, the number of the prisoners was drastically reduced and, consequently, several agriculture activities progressively stopped (Ministero dell'Interno, 1910, Ministero della Giustizia, 1923).

In the 1997 the territory of Pianosa was formally included in the National Park of the Tuscan Archipelago and since than it is a site for natural conservation. In 1998 the penitentiary was completely dismissed.

Agricultural history

Information on the techniques of crop rotation used at Pianosa in the last Centuries were obtained from historical documents archived at the Portoazzurro Penitentiary (Elba Island).

In the 1836 Zuccagni-Orlandini reported the use of a simple succession of crop with pasture. In the early 1900 a remarkable diffusion of *Phylloxera vastratix* seriously damaged the grapes and the interested areas were temporarily assigned to the cultivation of leguminous plants. Only several years later these fields went back to vineyard. However, for many years the most frequently used crop rotation was: 1st year *Vicia fabae* or *Avena sativa,* 2nd year *Triticum aestivum* or *Hordeum vulgare,*3rd year annual pasture, after 3 years of cultivation fields were fallowed.

More recently the agriculture activities of the Penal Colony were based on the cultivation of cereals (wheat and barley) and annual pasture.

A summary of land uses during the last century on the Pianosa island from the documents founded at Portoazzurro Penitentiaryis reported in Table 2.

Pianosa_LAB project

The Pianosa_LAB is a research network established in the 2000, when 5 Institutes of the National Research Council (CNR) and 4 University Departments created an innovative infrastructure aimed at the long-term monitoring of the actual exchange of carbon, water and energy among the biosphere and atmosphere of the island. Key objective of the Pianosa_LAB project is the determination of the C balance of the Pianosa island, thus, it significantly contributes to the understanding of the role of Mediterranean ecosystems as sinks or sources of atmospheric CO_2. Additionally, the project

Table 2: Land uses (ha) of Pianosa island in the last century

Year	Arable Fields	Vineyard	Vegetable Gardens and Orchards	Pasture	Woods	Total
1910	153	8	6	52	-	385
1923	153	25	8	52	9	414
1997	113	5	3	279	305	705

aims at monitoring on the long term the vegetation dynamics on the island also in view of the future conservation management plans proposed for the island

Research program and methodology

The above objectives are pursued through the quantification of C stores in soils and vegetation and through the quantification of biosphere-atmosphere carbon, water and energy fluxes, from the scale of singular leaf, up to the three identified ecosystems and to the entire island. The obtained data set is used to validate models, which simulate environmental and climatic effects on biosphere and atmosphere gas exchange processes.

The project is realised through a series of intensive fieldwork campaigns on the island of Pianosa, to which the researchers participate in collaborative activities. During the past two years of study, several field-work campaigns took place, generally in October and May of each year. In addition to these intensive campaigns, meteorological data were collected by the above mentioned meteorological station (Fig. 2 and 3), moreover from March 2002, CO_2 and energy flux measurements are running continuously using an eddy covariance flux tower installed on the Island (Vaccari *et al*., 2000).

The Project Work Plan

Given the integrated nature of this project and to improve activities' coordination and effectiveness, the Piansa-Lab is structured in working packages (WP) each of one with its specific tasks, and they are:

WP1- Soil Carbon sequestration and heterotrophic processes

This WP aims at producing a geo-referenced map of the organic soil C of the island and to evaluate the soil condition in relation to land use and past management practices. Products of this WP are, a part from a map of soils C distribution (Pezzarossa *et al.,* 2000), the quantification of soil organic carbon of the island, the evaluation of soil organic C sequestration through studies of SOM dynamics and the determination of turnover times of leaf litter and measurement of soil CO_2 efflux (Cotrufo 2000).

WP2 -Vegetation analyses and ecophysiology

The main activities of this WP were to evaluate the structure and productivity of the main ecosystems found on the island. For this scope species composition, leaf area index and extension of the main ecosystems were evaluated. Moreover, dominant species of the island were identified and their ecophysiology was characterized in terms of photosynthetic activity , above ground biomass and volatile organic carbon (VOC) emissions (Colom *et al*., 2000; Baraldi *et al*., 2000). Similarly to WP1, a GIS map of the actual main ecosystems found on the island was obtained. The activities of this WP could permit an up-scaling from leaf gas-exchange model to canopy and ecosystems gas-exchange models.

WP3 – Biosphere-atmosphere gas exchanges

Within this WP, measurements of CO_2 and H_2O fluxes by eddy correlation and by an atmospheric profiling system, based on the Vertical Mass Profiler, are carried out. Beside, measurements of volatile organic carbon (VOC) emissions from the dominant plant species are performed at leaf and branch scale by mean of leaf cuvette and bag enclosures. VOC vertical profile are also assessed at the ecosystem scale to quantify the contribution of VOC to ecosystem carbon fluxes (Vaccari *et al*., 2000; Baraldi *et al*., 2000)

WP4 - Isotopic discrimination

The biochemical and physical basis of isotopic discrimination by photosynthesis has been well established (Flanagan and Ehleringer, 1998). Leaf $\delta^{13}C$ reflects the $\delta^{13}C$ of tropospheric and canopy CO_2, and it is dependent on the turbulence regime and ecosystem physiology. On the contrary, no discrimination is associated to respiration processes, thus soil CO_2 efflux carry the isotopic signature of C of SOM and roots. Whilst for root $\delta^{13}C$ the same applies as described for leaf $\delta^{13}C$, the $\delta^{13}C$ of SOM reflects the $\delta^{13}C$ of the vegetation under which it was formed, and tends to increase with time and soil depth (Ehleringer *et al*., 2000). Ecosystem C isotope discrimination integrates all autotrophic and heterotrophic C fluxes, and applying the mass balance of stable isotopes, can be calculated knowing the $\delta^{13}C$ of the CO_2 respired by the ecosystem, and the corresponding tropospheric $\delta^{13}C$ (Buchmann and Kaplan, 2001). Carbon isotope discrimination is reliable in investigation of water use efficiency of C3 plants (Farquar *et al*., 1989). The isotopic approach is particularly suitable for environmental studies since it is not invasive and gives information on different time scale of plant physiology. Additionally, the isotope approach allows partitioning of different component of C fluxes (Yakir and Sternberg, 2000). Task of this WP is the determination of CO_2 isotopic composition in air, in relation with the activities of WP2 and WP3. Analyses of $\delta^{13}C$ in foliar, litter and soil samples are performed to trace soil C fluxes (Cotrufo *et al*., this issue), and water use efficiencies of the different plant species insisting on the island.

WP5 - Modeling activities

The C balance, determined over a variety of vegetated surfaces, represents one of the most interesting studies in the frame of the development of environmental modeling and especially as far as concern the planetary boundary layer (PBL). On the base of such considerations, a major objective of this WP is the description of this atmospheric layer and its evolution by means of simple atmospheric models. Thus, a micrometeorological 'operative' diagnostic model is developed, suitable to parameterize the daily evolution of the planetary boundary layer and to furnish the average aerodynamic and turbulent parameters under the varying atmospheric stability conditions. Along with the micrometeorological model, a surface resistance model is developed to study the surface heat and mass exchange. For this purpose, measurements of average potential temperature, friction velocity, sensible heat flux and potential temperature gradient, furnished by WP3 are used. In order to realize and to check the model a Similarity Theory approach is used by means of measurements performed by WP3 (Nardino *et al*., 2000).

The Research Group

The Research Institutes and University Departments involved in the Pianosa_LAB are:

National Research Council – CNR

- IBAF - Institute of Agro-forestry and Environmental Biology; Porano

- IBIMET - Institute of Biometeorology, Bologna-Firenze
- ISAC - Institute of Atmospheric Sciences and Climate, Bologna
- ISAFOM - Institute for the Mediterranean Agroforestry Systems, Napoli
- ISE - Institute for Ecosystems Studies, Firenze, Pisa Universities
- Department of Crop Science and Agricultural Engineering, Udine;
- Department of Agronomy and Agroecosystem Management, Pisa;
- Department of Agronomy and Land Management, Firenze;
- Department of Environmental Sciences, Second University of Naples, Napoli.

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