An Analysis of Carbon Storage in Protected Areas with Relation to Agroforestry Management and Biodiversity

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Abstract

Sicilian Protected Areas (PA: natural reserves and regional parks) are very heterogeneous, not only from a nature point of view but also from a management perspective, as within them various agricultural, pastoral and forestry activities take place. These agro-ecosystems play an important role for local flora and fauna. In fact, the lives of many organisms, especially birds, are linked to (and even dependent upon) human activities (pastures and cereal crops fields). For these reasons, it is important to maintain or increase both the nature value and environmental functioning through sustainable agricultural and forestry activities.

The study area of this paper is the "Grotta di Santa Ninfa" Nature Reserve, a 1.5 Km^2 PA in the Belice Valley (Trapani Province). It was established to protect areas of natural interest, the most important being a cave and its karstic system that feeds the underground watercourses. The way agricultural and semi-natural ecosystems within the drainage area are managed directly influences local erosion processes and, consequently, the conservation of this watershed.

The landscapes of the PA are also a result of centuries of human activity. The main units of vegetation are artificial woods (i.e. *Pinus halepensis* Mill., *Eucalyptus camaldulensis* Dehnh. and *Pinus pinea* L. plantations), garrigues, high woody pre-forest formations (i.e. the evergreen *Laurus nobilis* L. maquis and several mantle spots), while the most widespread agricultural uses are vineyards and cereal crop cultivation. We recorded quite a striking correlation between some sustainable agricultural and forestry management policies and the increase of carbon stock and permanence in the soil. In particular, the different soil management of vineyards (reduction of tillage) increases the carbon content of the soil. In the semi-natural plant coenoses, high woody pre-forest formations, which represent the more complex local communities, play a major role in carbon storage. In addition, artificial woods have an important part to play in carbon stocking. However, in order to develop a more natural landscape, and to improve the effect of carbon storage in the soil, exotic tree species should be replaced with autochthonous ones.

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Introduction and aims of the study

Agriculture and forestry represent crucial factors in the safeguard of the natural heritage of European Protected Areas because very often these land use forms occur within PA. During the last few decades, in Sicily human activities have caused serious damage to PA because of land use change and the disappearance of traditional management methods (Pasta and La Mantia, 2001a; La Mantia, 2006; La Mantia et al., 2007; Massa et al., 2007). This is particularly true for vineyards, where a continuous increase in soil tillage (up to eight along the cropping year) and an increased use of chemical weed control has been noted (in order to reduce soil evaporation, to enhance soil water retention capacity and to remove weeds (Gristina et al., 2004)). Such a technique, on the one hand, helps to achieve the target yield, but on the other hand it not only has a negative effect on the landscape and vegetation but also accelerates soil erosion. According to Tropeano (1983), this may be estimated at between 47 and 70 t ha^{-1} thus causing, in the medium term, a great reduction in the level of soil fertility. According to Pisante (2001), the last 30 years have been characterised by a significant loss of organic matter soil content (more than 50%!). Moreover, within the PA under study, erosion processes, compounded by local geomorphology, physical and chemical soil characteristics, directly affect the karstic hypogeous system and especially the main cave (situated within the "A" zone, below, and subject to maximum protection), which is connected to a spring located in the lower part of the PA. The most significant manifestation of this erosion is the obstruction of ponors and swallets by eroded materials, affecting the whole water feeding system of the cave.

An effective strategy to limit soil erosion processes and to preserve the natural value of the PA is as follows: 1) to change local soil management within the agricultural areas and adopt more conservative techniques, as already successfully tested in several vineyards in similar contexts (Gristina et al., 2004), 2) to use species able to guarantee a higher canopy and diversity level in afforestation practices, and 3) to adopt lower impact afforestation techniques. The aim of our research was to identify the points of weakness in the local land use system and to validate some agronomic techniques able to control (or at least reduce) agriculture and forestry impact on the local ecosystems (La Mantia and Pasta, 2001a). Thus, our PA represents a field laboratory, where the effectiveness of new sylvicultural and agronomic techniques can be tested, with a view to defining new conservation and management policies that could be applied within other Sicilian PA's. The overall evaluation of the adopted conservation techniques was made using a multidisciplinary approach, considering not only agronomical aspects, but also environmental and socio-economic ones.

Study area description and management problems

The "Grotta di Santa Ninfa" Nature Reserve is located about 2.5 Km E-NE from the towns of Santa Ninfa and Gibellina (Trapani Province). The total PA surface area is about 130 ha, its altitude ranges between 400 and 625 m.a.s.l., its longitude between 12°53'45" and 12°55'10" E and its latitude between 37°46'50" and 37°47'50" N (Fig. 1).

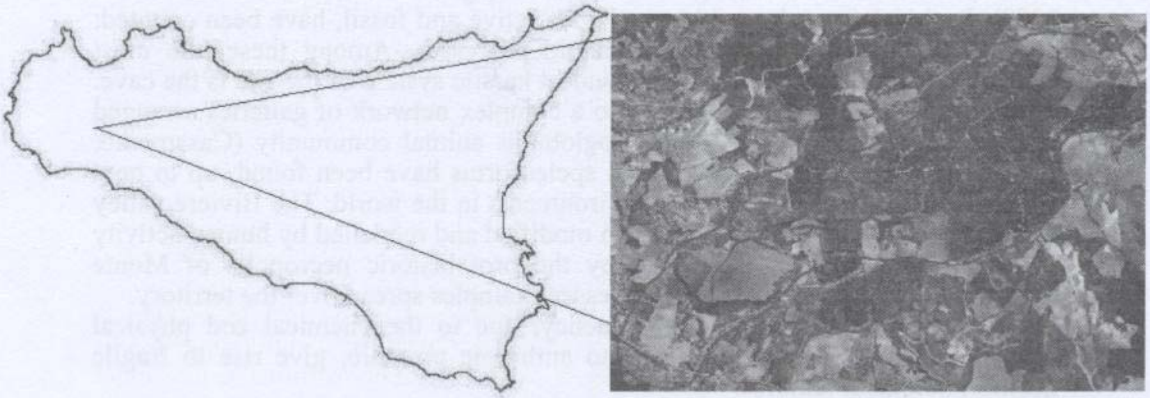

Fig. 1: Localization of the study area and perimeter of the "Grotta di Santa Ninfa" Protected Area.

The PA is characterised by a landscape typical of hilly areas, inland of the Belice Valley (western Sicily), although the overall ecology has been altered by widescale *Eucalyptus* and *Pinus* plantations dating back to about 40 years ago. The main peaks, some of which are of significant archeological interest (Casamento and Palmeri, 2001), are "Monte Finestrelle" (663 m a.s.l.), "Fontana Blandina" (623 m a.s.l.), Montagna della Magione (562 m a.s.l.) and "Monte Castellaccio" (547 m a.s.l.).

The Nature Reserve was established according to Art. 4 of Regional Law n. 14 (August 9th 1988) as a fulfillment of the Parks and Reserves Regional Program, aiming to "*preserve in all its integrity the natural environment, due to the remarkable opportunities to study current and past hydrology, speleogenesis, aspects linked to the development of special mineralisations...*". In addition to the above, there are other important features of the local natural heritage (Casamento and Palmeri, 2001), mostly relating to geomorphological features resulting from surface and underground karstic phenomena, but also relating to remarkable plant communities, such as the *Laurus nobilis* riparian maquis and the local patchwork of grassland and garrigue on gypsum outcrops (Pasta and La Mantia, 2001b). In fact, the PA lies within a wider "Site of Community Interest" named "Complesso dei Monti di Santa Ninfa-Gibellina e Grotta di Santa Ninfa" (Code ITA010022), established in accordance with EEC Directive 92/43, due to the presence of 4 habitats of Community Interest and of many wild animal species of high bio-geographical and/or conservational interest. In accordance with the directive, the PA territory has been divided into two areas, each with a different designated use due to their different environmental value. Zone "A" (= reserve) corresponds with the hypogeous system (ponor-cave-resurgence), approx. 1,350 m deep, and encompassing two areas surrounding the entrance of the cave and the ponor. Zone "B" (= pre-reserve), is approx. 140 ha, including the "Biviere" blind valley, roughly represents the feeding basin of the cave. The Biviere stream has a semi-perennial water regime – the only one within the territory – with a 2.5 km long fluvial course (Agnesi et al., 1989; Celico et al., 1989). In the plateau about 40 caves, both active and fossil, have been counted; their genesis is mostly linked to karstic processes. Among these, the most complex and varied representing the widest karstic system of the site is the cave. Its evolution is ongoing, giving rise to a complex network of galleries arranged on many levels, hosting a unique troglobious animal community (Casamento, 2001). Inside the cave many original speleoforms have been found, up to now the only ones in karstic gypseous environments in the world. The Biviere valley mostly constitutes a land that has been modified and modelled by human activity since ancient times, as evidenced by the protohistoric necropolis of Monte Finestrelle and by a number of other lesser examples spread over the territory.

Slope process intensity and frequency, due to the chemical and physical characteristics of the rock and due to anthropic pressure, give rise to fragile geomorphological features.

Within the territory of the PA given over to agricultural activity, various kinds of land uses can be identified, mostly linked with traditional techniques: vineyards (prevailing), arable lands, horticultural crops, olive groves, pastures, fallows and afforested areas.

On the slopes of the gypseous hills only a few scattered and species-poor spots of low evergreen thermophilous maquis [*Pistacio lentisci-Chamaeropetum humilis* Brullo et Marcenò 1985 or *Rhamno alaterni-Euphorbietum dendroidis* (Trinajstič 1973) 1984 em. Géhu et Biondi 1987] are present, while an interesting *Laurus nobilis*-dominated hygrophylous shrubland and some scattered *Pruno-Rubion ulmifolii* O. de Bolòs 1954 mantle fragments grow within and along the Biviere stream. Local semi-natural vegetation is more frequently observed as a patchwork of discontinuous garrigue formations (*Cisto-Ericion multiflorae*), perennial grassland (*Hyparrhenion hirtae* and *Avenulo-Ampelodesmion mauritanicae*), therophytic prairie (*Trachynion distachyae*) and rupicolous assemblages (*Dianthion rupicolae* Brullo et Marcenò 1979). The artificial forest plantations of the PA are mostly formed by *Pinus* spp. and *Eucalyptus camaldulensis*. The latter are the less interesting from a naturalistic point of view. Fallows and hedges are often characterized by species-poor assemblages such as *Bromo-Oryzopsion miliaceae* O. de Bolòs 1970 (subhygrophilous *Arundo collina* and dominated grassland *Euphorbia ceratocarpa*), while most of the Biviere stream is covered by reeds (*Phragmition communis* W. Koch 1926).

Material and methods

Land use

Current land use and its evolution was studied by analyzing the 1972 and 2005 aerial photos of the site and then analysing the data using the Technical Regional Map (1:10,000 scale). Interpretation of the 1972 aerial photos allowed us to evaluate the effects of the protection of the PA and indirectly to detect effects of land use modifications on soil conservation. In drafting the current land use map, interpretational keys were compiled using direct surveys in the sample areas with the most representative land use classes (La Mantia and Pasta, 2001b). The data from the field working map were analysed using ARC/INFO software to quantify the number of patches belonging to each land use unit in the study. Land use class nomenclature follows the "CORINE Land Cover" convention in order to facilitate data comparison at a European level.

Flora and vegetation

Vegetation studies were carried out over two years in order to understand the effects generated by different land uses on the floristic composition of the plots and, above all, to evaluate the effects of the experimentally introduced modifications. With this aim, a trial was carried out to analyse the different plant communities of the "Grotta di Santa Ninfa" Nature Reserve. In particular, we expected to obtain some quantitative information both on α-biodiversity (i.e. species richness) and on the dynamic trends of some of the most representative units of local landscape, with special attention to those cultivated areas that have undergone some changes in applied agronomical techniques. Thus, we selected several plots referred to as the following landscape units: Semi-natural landscape ("shrubland", including maquis and mantle fragments; "garrigue and grasslands", including xeric *Ampelodesmos mauritanicus*-dominated and *Arundo collina*-dominated ones); Artificial forests and *Euphorbia ceratocarpa* (pure *Eucalyptus camaldulensis* plantations; pure *Pinus halepensis* plantations, pure *Pinus pinea* plantations, mixed conifer plantations, sparse plantations); Agricultural landscape (cereal crops, vineyards and olive groves).

To allow comparisons between the *relevés* from different plots, they all shared the same standard size (100 m^2). Vascular plant classification follows Pignatti (1982), Greuter et al. (1984-1989) and Tutin et al. (1964-1980, 1993).

Every plant species within the plot was assigned a Braun-Blanquet (1932) cover/dominance index, following the more recent scale proposed by Pignatti and Mengarda (1962).

During data evaluation, each *relevé* was used to check the variation of: 1) total number of taxa; 2) total number, percentage and cover percentage of each taxon, with particular attention on the pioneer and nitrophilous taxa, referred to the class *Stellarietea mediae* R. Tx. Lohmeyer et Preising ex von Rochow 1951, linked to nutrient storage (or degradation) processes in the soil; 3) total number, percentage and cover percentage of each biological form (Raun Kiaev, 1934), to verify eventual increases in vegetation structure complexity or eventual amelioration of hydrological function of the plant communities being examined.

Soil features

50 soil augerings were made spread across the study area. We determined depth, colour, soil skeleton, sand, loam and clay and carbonates. Based on preliminary information collected from the soil augerings, nine soil profiles were surveyed and allowed us to create the soil map of the "Grotta di Santa Ninfa" Protected Area.

Besides, 324 soil samples were collected (both 0-20 cm and 20-40 cm deep) following a regular grid pattern and analyzed for organic carbon following the Walkley-Black (1934) method.

Geostatistical procedures were followed to analyze data at both depths. CO_2 soil fluxes were measured monthly from January to July using a CIRAS infrared detector. Forty such procedures were done (about 7,700 measurements in total). Soil temperature and moisture were also measured. An average annual data set for each different type of land use was obtained (by integration) for each type.

Current cropping techniques and condition of artificial woods and semi-natural vegetation

A survey and mapping of the cropping techniques in use for each crop was carried out. Once catalogued, they were used as input as separate items in ARC/INFO. The land use classes underwent cross-checking with the data relating to the hydrologic and morphologic soil characteristics, assigning to each of them a score in terms of erosive risk. The state (α-diversity, canopy cover) of the closed afforested and open (garrigues, sparse afforested) areas was evaluated on young plantation, and to evaluate the effects due to these differences on the major biotic, chemical and physical soil features.

Land cover

Land cover change was evaluated by using vegetation indexes. Vegetation indexes are reflexed and adsorbed energy algebraic combinations and are correlated with the biophysical parameter of the photosynthetic active vegetation (biomass, density, water content, etc.). The widely used indexes are calculated using very simple functions such as Red ("R") and Near Infrared ("NIR") wave length. The Normalised Difference Vegetation Index ("NDVI") gives a very useful index for canopy structure characterization (Nelson and Holbe, 1986; Lawrence and Ripple, 1988). It is estimated using 3 and 4 spectral bands and calculated as: NDVI = (NIR-RED)/(NIR+RED) where NIR is 4 band reflectance (Near Infrared reflectance) measured by the Thematic Mapper sensor and where RED is 3 band value (Red reflectance).

NDVI values range between -1 and 1, where zero means complete absence of vegetation and higher values mean vegetation abundance (Singh, 1989). NDVI is also strongly related to vegetative cover index (Tucker, 1979) and to leaf area index (Liu and Huete, 1995). Radiometrically adjusted LANDSAT images (1987, 1995 and 2005) were used for NDVI calculation.

To avoid errors in land cover evolution calculation due to sensor calibration differences, we considered the NDVIin (= within reserve area)/ NDVIout (= out of the reserve area) index with reference to the LANDSAT images.

Table 1: Land use change between 1972 (beginning of reforestation activity) and 2005.

Land use	1972		2005		Change
	ha	%	ha	%	(%)
Shrubland	-	-	2	1.4	
Garrigue and grassland	87	62	23	16.7	-73
Mixed vegetation	-	-	7	5.1	
Ruderal vegetation	-	-	6	4.4	
Hygrophylous vegetation	-	-	2	1.3	
Pure *Pinus pinea* plantations	-	-	2	1.2	
Mixed conifer plantations	-	-	1	0.4	
Pure *Pinus halepensis* plantations	-	-	21	14.7	
Pure *Eucalyptus* plantations	-	-	15	10.	
Sparse plantations	-	-	23	16.8	
Water reservoirs	-	-	4	2.8	
Cereal crops	46	33	4	3.1	-91
Vineyards	5	4	28	19.9	+434
Olive groves	1	1	2	1.3	+32
Total	140	100	140	100	

Results

Land use, flora and vegetation

Significant changes in land use within the PA were recorded, especially relating to afforestation activity (Table 1). This has strongly affected the areas once covered by semi-natural pre-forest vegetation by significantly reducing the surface areas once occupied by garrigue and grassland communities, thast locally play the most important role in maintaining local α-diversity and floristic heritage (Table 2). Shrubland communities shall be considered as "woody plant reservoirs", playing a major role in progressive succession processes. Unfortunately, it is quite difficult to appreciate any significant change on the extension of the surfaces covered by this land use unit since 1972. The class "mixed vegetation" refers to those (small) areas where two or more land use classes actually coexist: the increase of the surface areas devoted to this land use unit is mostly due to agriculture abandonment. "Ruderal vegetation" *Stellarietea mediae* communities experienced a strong increase along with the increase of vineyards. Even if the hygrophilous communities growing along the stream and on the margin of the "water reservoirs" are of great interest for their faunistic role, they have been neglected due to the small total surface area of the patches devoted to this land use unit. In fact, they were not detectable in the 1972 aerial photo due to past disturbance deriving from regular "cleaning" practices. Artificial woody plantations strongly affected local landscape; it would be more useful to differentiate dense and mature stands from those where tree distribution is scattered and discontinuous due to fire or because they have been planted only recently. We have shown the gaps in artificial plantation in the illustrative Figure 2. Among the land use unit "sparse plantations", the areas characterised by *Acacia* spp. and/or other exotic broadleaved trees have been neglected, as they are small, localised and of little interest. Cereal crop areas have been substituted with artificial woods and vineyards. Among agricultural land units, olive groves surfaces experienced very slight modifications (Fig. 2).

Table 2: Conservation role of the studied land use units

Land Use Units	Rare, endemic or protected plants	Habitat listed within 92/43 EEC Directive (*priority habitat)
Shrubland	-	*matorral di *Laurus nobilis*[1]
Garrigue and grassland and sparse plantations	*Anacamptis pyramidalis*, *Asperula aristata* subsp. *longiflora*, *Biscutella maritima*, *Carlina sicula* subsp. *sicula*, *Dianthus siculus*, *Gypsophyla arrostii*, *Himanthoglossum robertianum*, *Magydaris pastinacea*, *Neotinea intacta*, *Odontites rigidifolia*, *Ophrys bombyliflora*, *Ophrys* cfr. *lupercalis*, *Ophrys grandiflora*, *Ophrys obaesa*, *Ophrys panormitana*, *Ophrys sicula*, *Ophrys speculum*, *Orchis italica*, *Pimpinella anisoides*, *Scorzonera deliciosa*, *Serapias lingua*, *Serapias parviflora*, *Silene sicula*, *Tragopogon cupanii*	thermo-mediterranean and pre-desert scrub + *pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*
Mixed vegetation	-	-
Ruderal vegetation	*Euphorbia ceratocarpa*	-
Hygrophylous vegetation	-	-
Pure *Pinus halepensis*, Pure *Pinus pinea*, sparse plantations and mixed conifer plantations	*Anacamptis pyramidalis*, *Himanthoglossum robertianum*, *Carlina sicula* subsp. *sicula*, *Ophrys* cfr. *lupercalis*, *Ophrys panormitana*, *Ophrys sicula*, *Orchis italica*, *Pimpinella anisoides*, *Silene sicula*	thermo-mediterranean and pre-desert scrub + *pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*[1]
Pure *Eucalyptus* plantations	*Himanthoglossum robertianum*, *Carlina sicula* subsp. *sicula*	-
Cereal crops	-	-
Vineyards and Olive groves	*Convolvulus tricolor* subsp. *cupanianus*	-

[1]Degraded and/or species-poor features

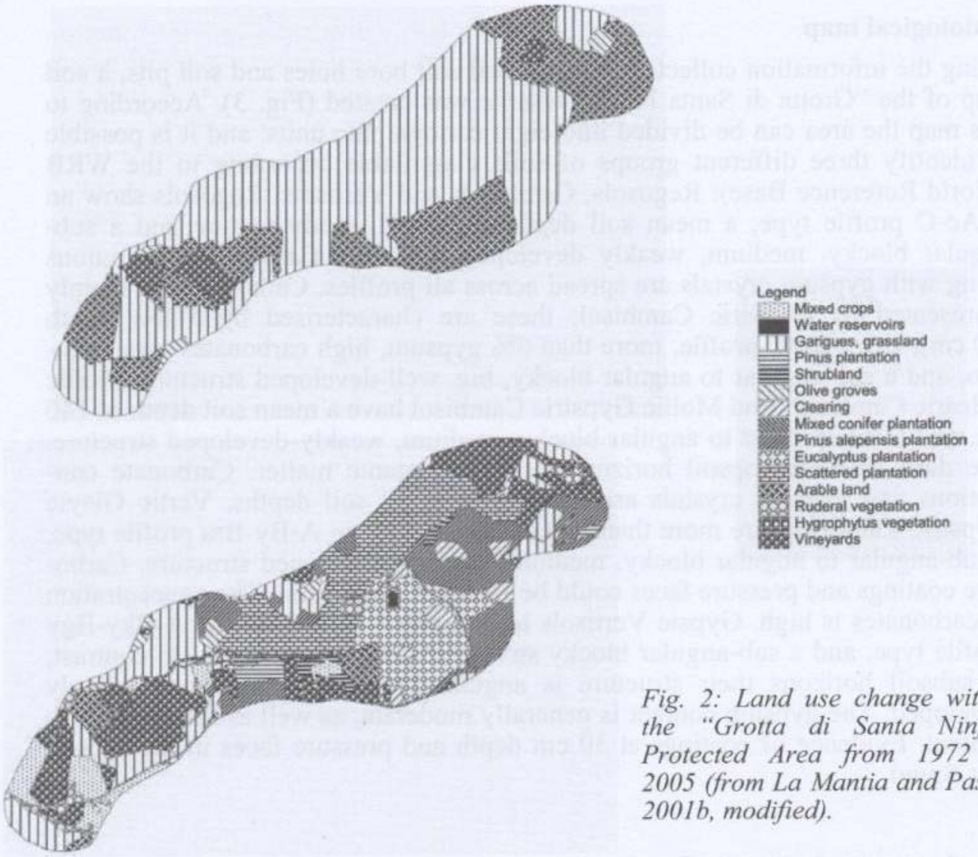

Fig. 2: Land use change within the "Grotta di Santa Ninfa" Protected Area from 1972 to 2005 (from La Mantia and Pasta, 2001b, modified).

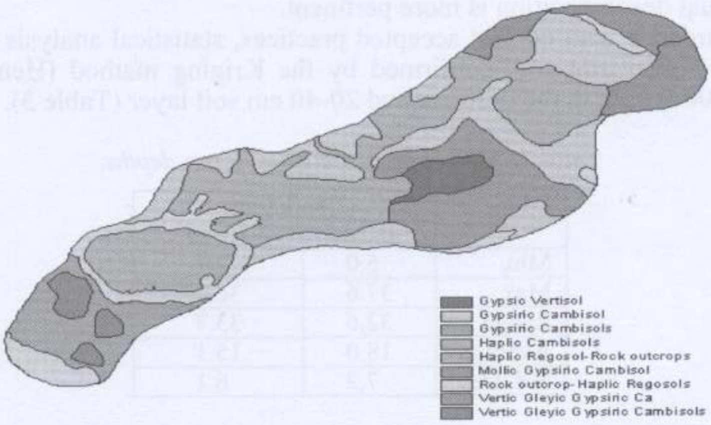

Fig. 3: Pedologic map of the "Grotta di Santa Ninfa" Protected Area.

Pedological map

Using the information collected from several soil bore holes and soil pits, a soil map of the "Grotta di Santa Ninfa" reserve was created (Fig. 3). According to this map the area can be divided into eight cartographic units, and it is possible to identify three different groups of soils classifiable according to the WRB (World Reference Base): Regosols, Cambisols and Vertisols. Regosols show an A-Ac-C profile type, a mean soil depth of 90 cm, sandy texture and a sub-angular blocky, medium, weakly developed structure. Carbonate concretions along with gypsum crystals are spread across all profiles. Cambisols are mainly represented by Gypsiric Cambisol; these are characterised by a low depth (70 cm), an A-By-C profile, more than 5% gypsum, high carbonates concentration, and a sub-angular to angular blocky, big, well-developed structure. Mollic Calcaric Cambisols and Mollic Gypsiric Cambisol have a mean soil depth of 140 cm, and a sub-angular to angular blocky, medium, weakly-developed structure. The dark coloured topsoil horizon is rich in organic matter. Carbonate concretions and gypsum crystals are spread across all soil depths. Vertic Gleyic Gypsiric Cambisols are more than 110 cm deep, with an A-By-Bss profile type, a sub-angular to angular blocky, medium, strongly-developed structure. Carbonate coatings and pressure faces could be found in the subsoil. The concentration of carbonates is high. Gypsic Vertisols have a depth of 100 cm, an A-Bky-Bgy profile type, and a sub-angular blocky structure in topsoil horizons. In contrast, in subsoil horizons their structure is angular blocky, medium and strongly developed. The gypsum content is generally moderate, as well as the carbonates content. Evidence of coatings at 30 cm depth and pressure faces in the subsoil was found.

Land cover and change of carbon content

Average soil carbon content was found to be higher in the top soil layer where crop residual decomposition is more pertinent.

In accordance with current accepted practices, statistical analysis of the data showed a high variability, confirmed by the Kriging method (Heuvelink and Wesber, 2001) both in the 0-20 cm and 20-40 cm soil layer (Table 3).

Table 3: SOC (g kg-1) statistics at two depths.

	Depth (cm)	
	0-20	20-40
Min.	5.0	2.7
Max.	37.6	36.3
Range	32.6	33.7
Average	18.0	15.1
Std. Dev.	7.2	6.1

Not only pedological differences are responsible for such variability but also slope, different soil use and particularly land use changes (afforestation, etc.) since 1972.

Table 4: Carbon fluxes and carbon content evolution in different land use units.

	Land use							
	Pure *Eucalyptus* plantations	Garrigues and grassland	Shrubland	Olive groves	Pure *Pinus pinea* plantations	Pure *Pinus halepenses* plantations	Cereal crops	Vineyards
CO_2 fluxes ($t\ ha\ y^{-1}$)	1.4	2.6	*2.8*	2.4	2.0	2.0	1.8	2.1
Soil C ($t\ ha^{-1}$)	62.4	98.8	*130.0*	119.6	83.2	78.0	72.8	111.8
Differences to shrubland (t)	67.6	31.2	----	10.4	46.8	52.0	57.2	18.2
Differences to shrubland ($t\ y^{-1}$)	2.4	1.0	----	0.3	1.6	1.7	1.9	0.6

Higher carbon contents correspond to mantle spot land use units (Table 4) and in general to areas not cultivated during the last few decades. In fact, while no significant carbon accumulation was recorded during the first years after afforestation (Paul et al., 2002), shrubs do provide a more stable carbon content over time (Brejda, 1997) (Fig.4).

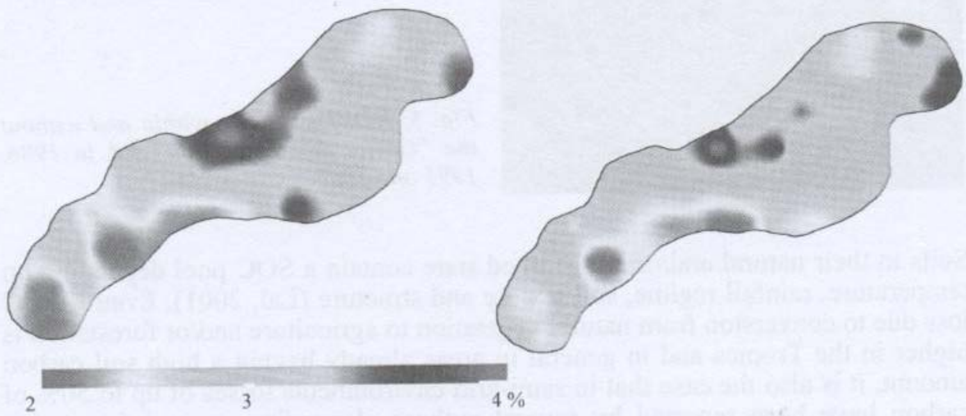

Fig. 4: SOM spatialization in the "Grotta di Santa Ninfa" PA (left: 0-20 cm layer and right: 20-40 cm).

A high soil carbon reduction (in comparison with mantle spots) has been recorded (values between 46 and 67 t ha^{-1}) for all kinds of vegetation subject to human impact since the beginning of reforestation (1972). No correlation between soil organic content (SOC) distribution and other morphometric variables (altitude, slope, etc.) was found, thus underlining the importance of pedological type in the maintenance and the increase of soil carbon over time.

NDVIin/NDVIout rate calculation enables correct evaluation of land use evolution and reforestation effectiveness. From 1987 to 2005 the rate increased from 0.95 to 1.03 and then up to 1.15 in the last year. NDVI rate increase takes on a very important meaning because it is exclusively due to local afforestation activity in the area (Fig. 5).

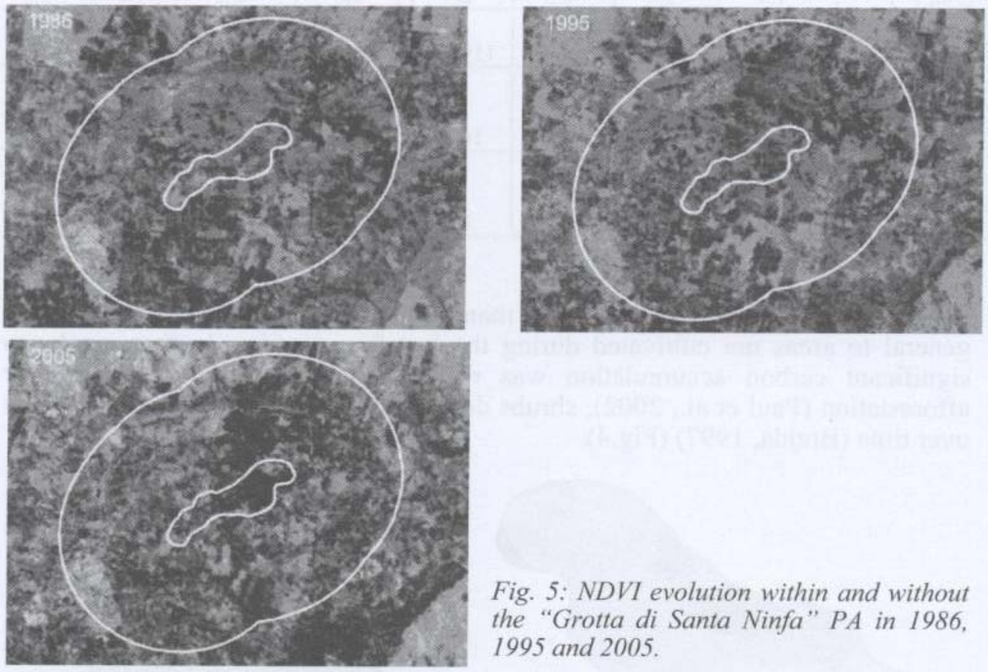

Fig. 5: NDVI evolution within and without the "Grotta di Santa Ninfa" PA in 1986, 1995 and 2005.

Soils in their natural and/or undisturbed state contain a SOC pool depending on temperature, rainfall regime, soil texture and structure (Lal, 2001). Even if SOC loss due to conversion from natural vegetation to agriculture and/or forestation is higher in the Tropics and in general in areas already having a high soil carbon amount, it is also the case that in semi-arid environments losses of up to 50% of carbon have been reported by several authors, depending upon deforestation and/or cultivation of virgin soils. In our case study we consider the shrubland as a "virgin soil" because this community represents the most mature local vegetation-type.

Differences between shrubland soil carbon content (carbon ecological level) and carbon content in other land use units range between 10.4 and 67.6 t ha^{-1} for olive groves and *Eucalyptus* plantations, respectively (Tables 3 and 4).

Trying to estimate annual CO_2 fluxes since the beginning of afforestation, assuming that 1 g of soil carbon = 3.5 g of CO_2 and given a constant mineralization rate during the 30-year period since afforestation began (1972), land use change in the PA determined CO_2 fluxes from soil to the atmosphere of about 1.2 and 7.9 t ha^{-1} year^{-1}.

Average CO_2 fluxes in the PA were about 24 mg m^{-2} h^{-1}, showing a high variability in relation to vegetation-type: minimum values were recorded on *Eucalyptus* plantations (17 mg m^{-2} h^{-1}) and maximum ones on shrubland vegetation (32 mg m^{-2} h^{-1}) (Table 4).

Conclusions

Sustainable agro-forestry practices really do increase carbon stock and its stability in the soil. The results were particularly striking in the vineyards subject to a reduction of tillage.

Among the local semi-natural plant communities, maquis represents the more complex formation and plays the most important role for carbon storage. Mantle spots, grasslands and garrigues are the most important communities for biodiversity conservation. Functional aspects such as diversity and soil carbon budget management do not clearly show the correlation between plant community productivity (Net Ecosystem Production "NEP" or Net Primary Production "NPP") and soil carbon levels. The scant knowledge on the biophysical mechanisms of carbon return in the soil and the data here reported allow us to consider NEP (and/or NPP) a poor predictor of ecosystem productivity and ability in carbon sequestration.

A two year investigation using vegetation *relevés* is still insufficient to provide a full explanation of the dynamic trend of the flora within the studied plots: both vegetation cover and composition change seem to be strongly influenced by seasonal rhythms and, paradoxically, by human disturbance due to data collecting activities. The plots continue to be dominated, in terms of floristic composition and even more so when considering cover rates, by plants like *Stellarietea mediae* (i.e. nitrophilous herbs, mostly pioneers and/or ruderals, in areas disturbed by agricultural practices). Further investigation could lead to a better understanding of vegetation trends. A longer investigation, carried out in the neighbouring Salaparuta territory (Di Lorenzo et al., 1999), revealed an intense turn-over, especially in non-irrigated vineyards, and a general increase in the number of species (especially biennials and leguminous species).

Notwithstanding the limited time of our investigation, the data set collected provides a good tool to evaluate not only the effect of different cultural options on factors, such as nutrient content and soil erosion within cultivated areas, but also provides first-hand information on the biodiversity values recorded in the cultivated areas of the "Grotta di Santa Ninfa" Nature Reserve and within the semi-natural and artificial landscape units around them.

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