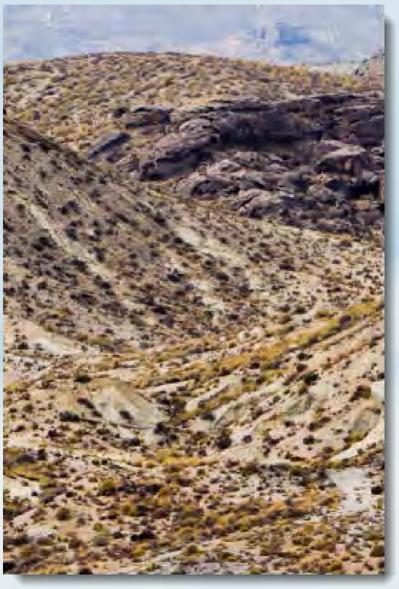
CASCADE

Catastrophic shifts in drylands:

How can we prevent ecosystem degradation?

CASCADE REPORT series



# Historical evolution of dryland ecosystems

*Authors: Ioannis Daliakopoulos, Ioannis Tsanis*

***Technical University of Crete, Greece***

Technical University of Crete

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| EU project representative: | Prof. Dr. C.J. Ritsema - (coen.ritsema@wur.nl)- +31 317 |
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| E-Mail(s): | daliakopoulos@hydromech.gr |
| Telephone Number: | +30 28210 37800 |
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## 1 - the Project Consortium

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|---|---|---|---|
| 1 | STICHTING DIENST LANDBOUWKUNDIG ONDERZOEK | ALTERRA | Netherlands |
| 2 | TECHNICAL UNIVERSITY OF CRETE | TUC | Greece |
| 3 | UNIVERSITA DEGLI STUDI DELLA BASILICATA | Unibas | Italy |
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# CASCADE

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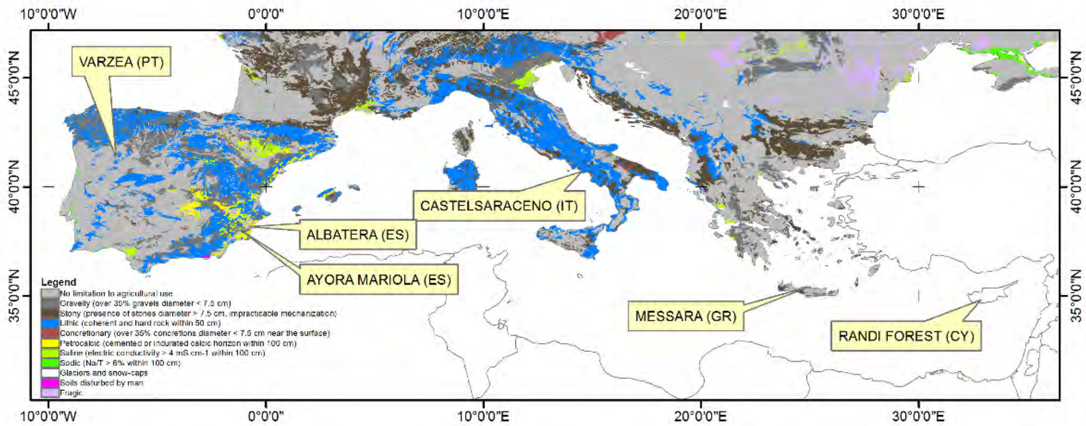
# Historical evolution of dryland ecosystems




Daliakopoulos, I.N & Tsanis, I.K.

Technical University of Crete

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# 1 Introduction

## 1.1 Definition of Dryland Systems

Water scarcity, the main characteristic of drylands, constrains their two major interlinked services - primary production and nutrient cycling (Safriel et al., 2005). The immediate cause of this scarcity is usually the long-term imbalance of moisture losses through evaporation from surfaces and transpiration by plants over the natural moisture inputs. This potential water deficit, that can also be triggered by non-natural causes, has great impacts on both natural and managed ecosystems, affecting crops, livestock and humans. Depending on the degree of water limitation and aridity, UNEP (United Nations Environment Programme) classifies drylands in four subtypes: dry subhumid, semiarid, arid, and hyper-arid. The level of aridity typical for each of these subtypes is given by the Aridity Index which is defined as the ratio of the mean annual precipitation to the mean annual evaporative demand, expressed as potential evapotranspiration. Aridity Index values lower than 1 indicate an annual moisture deficit and drylands are defined as areas with AI ≤ 0.65.

Using index values, the four dryland subtypes can be positioned along a gradient of moisture deficit. They all together cover more than 6 billion ha, or 41.3% of Earth’s land surface (Safriel et al., 2005), and occur on all continents (between 63N and 55S). Although the classification of an area as a dryland subtype can be determined by the Aridity Index, it is important to note that the inter-annual variability of precipitation in these areas can be large. Dryland subtypes can also be described in terms of their land uses: rangelands, croplands and urban areas. Rangelands and croplands jointly account for 90% of dryland areas supporting an integrated agropastoral livelihood. The Mediterranean Basin, which has a pronounced overall gradient of aridity from the northwest to the southeast (Bautista et al., 2010), consists of about 2.3 million $km^2$ of land, with the majority of the drylands in the European part of this region being in the territory of six southern European countries: Spain, Portugal, Greece, Italy and France (Puigdefábregas and Mendizabal, 2004) and Cyprus (which joined the EU in 2004).

## 1.2 Ecosystems in Drylands

The four dryland subtypes described above include a greater number of dryland ecosystems that can be aggregated into large, higher-order units known as biomes (Safriel et al., 2005). In the European drylands, four ‘‘broad’’ dryland biomes - desert, grassland, Mediterranean (mainly scrubland) and forest (mainly woodland), successively replace each other along the aridity gradient, with increasing aridity leading to an expected decrease in plant cover and health. The number of broad biomes that may occur within a dryland subtype also decreases with aridity, and the diversity of biomes peaks in the semiarid subtype, which also covers the largest area of the various subtypes. The presence of different biomes within each dryland subtype demonstrates that biological species respond to various environmental variables, such as soils and geomorphological and landscape features, apart from the overall moisture deficit.

## 1.3 Conditions and trends in drylands

As part of the natural environment, soil, much like water, forests, plants and animals is a global renewable resource, as long as it is adequately monitored, protected and conserved. Soil formation rates are so slow (Wilding et al., 1983) that the loss of its biological productivity or economic benefit leading to land degradation can be considered an irreversible process (Tsunekawa, 2000) on human timescales. While soil is a global asset, its ownership is often private and terms production and benefit are subjected to national, local or even individual priorities (e.g. transforming a cropland to grazing rangeland may simply alter the form of the biological productivity and source of profit but when land is intended for residential or industrial use, its degradation may be irrelevant). This means that the fate of soil is often dictated by the owner or user thus making it hard to put a price or leash on land pollution, degradation or scarcity (Daliakopoulos & Tsanis, 2013).

Aridity reduces the degree of soil development properties such as soil and infiltration depth, organic content and nutrients (Sombroek, 1990; Wilding et al., 1983), thus hindering primary production and ecosystem resilience. In semi-arid and arid areas the system does not have the capacity to absorb the significant pressures and land can become irreversibly non-productive (Van De Koppel and Rietkerk, 2000). Desertification, the state that implies irreversible degradation where all agricultural potential is destroyed, poses a grave and visible danger to the livelihood of the communities. The global impact of this risk is also significant for dryland rangelands that comprise approximately 80% of the world's rangelands (Branson et al., 1981) and support approximately half of the world's livestock (Allen-Diaz et al., 1996). Vegetation is the primary resource and stability factor in these rangelands and grazing shifts most of the primary production from vegetation to livestock thus limiting vegetation services.

In most Mediterranean basin drylands, the downward spiral of land productivity that ends up in desertification is driven by population pressure coupled with the degree of aridity (Safriel, 2006). Socioeconomic circumstances drive land use and forest exploitation, with fluctuations in human population being accompanied by fluctuations in land exploitation, with peaks of overgrazing, forest clearing for agriculture, forest overexploitation for firewood, charcoal production, and logging, intermingled with periods of land abandonment. In Southern Europe, fire has always been a major factor in shaping rural landscapes. Again, the fire phenomenon is closely related to land use and other human activities. The consequent impact on forests was the degradation of vegetation, the reduction of forest surface, the degradation of soil quality, and the increase of soil erosion and risk of flooding. During recent decades, the large increase in population, rise of living standards, development of irrigated agriculture, and new activities—especially tourism—have drastically changed the water uses (Cudennec et al., 2007). Agricultural intensification has led to contamination of soils and water with nitrates, pesticides, and even heavy metals (Stoate et al., 2001). Future needs will be hard to satisfy as many aquifers are already overexploited and surface waters are endangered (Kundzewicz et al., 2007; Tal, 2006). While Eurostat has estimated (Gras, 2009) that in the Euro-Mediterranean region population growth has been slowing and life expectancy increasing for the period 2000-2007, long term scenarios are more uncertain.

Likewise, the natural climate variability in the Mediterranean basin and the Middle East is very high (Lionello et al., 2006; Xoplaki et al., 2004) and related uncertainties are significant (Bacro and Chaouche, 2006). Throughout history, climate variability and intervals of intense land over-exploitation have contributed to episodes of land degradation (Brandt et al., 1996; Pons and Quézel, 1985), resulting in landscape changes that have often crossed ecological thresholds. The current state of the art on climate change research for the Mediterranean region indicates a strong susceptibility to change in hydrological regimes, an increasing general shortage of water resources and consequent threats to water availability (Koutroulis et al., 2012) and land degradation. Regarding precipitation, to date, no uniform regional pattern has been identified across the Mediterranean region (Cudennec et al., 2007). Particular local changes already identified may contradict each other, both at macroscopic scale (Piccarreta et al., 2004; Serrano et al., 1999; Slimani et al., 2007) and in detailed features as the number of rainy days or rainfall intensity (Alpert et al., 2002; Martín-Rosales et al., 2007). On the other hand, the warming trend in the Mediterranean over the past 30 years likely exceeds the warming rate of any other comparable period over the last 5 centuries (Luterbacher et al., 2004). A mean temperature increase of 3.4$^{o}$C is projected over the next century in the northern Mediterranean, with the greatest warming and highest variability in the summer (Solomon et al., 2007).

Finally, while climate and population are important, adverse conditions are often augmented by shortage of financial resources and institutions that are critical for arresting or avoiding this spiral (Mazzucato and Niemeijer, 2000), thus demonstrating that often aridity and poverty produce negative feedbacks. For example, agricultural land abandonment in the marginal uplands has severely impacted landscape structure and has led to deteriorating soils, increased erosion, and an ecological transformation moving towards bushland, scrubland and forestland expansion (Chauchard et al., 2007; Thornes and Wainwright, 2003; Vallejo, 2009). However, socioeconomic drivers are difficult to trace in order to answer whether poverty and its associated security issues is generated or driven by desertification.

## 1.4 Remote Sensing

Satellite Remote Sensing (RS) data were first available in the early 1970s. Since then, the rapid technological development in processing power and sensor sensitivity have resulted in a steady increase in the quantity and quality of information in terms of spectral and spatial accuracy. Surfaces with different coverage, each have a characteristic spectral reflectance (signature) that allows discriminating between them on RS products. The last generation of high-resolution Earth Observation satellites, e.g. SPOT-5, IKONOS, Quickbird and WorldView-1, provide images with a level of detail compatible with urban mapping (Jensen and Cowen, 1999), i.e. from 0.5 to 2.5 m spatial resolution. In addition, multispectral sensors have the advantage of recording Near Infra-Red (NIR) radiation which is the most sensitive spectral band used to map vegetation canopy properties (Guyot et al., 1990). Using this property, satellite RS can be effectively used for mapping current distribution of ecosystems globally, monitoring their status and improving the understanding of feedbacks between ecosystems and climate.

Land cover mapping is by far the most operational and cost effective application of RS for land resources assessment and monitoring. Land cover can be mapped from all optical satellite data ranging from NOAA AVHRR and SPOT Vegetation 1 km, to High Resolution (HR) or Very High Resolution (VHR) imagery. The most common and cost effective RS data used are the HR, and one in particular, the Landsat TM, considering its cost per km$^2$. Until recently, the study of vegetation changes in drylands has been hindered by the lack of spatially and temporally detailed imagery in the high resolutions required for this type of analysis (e.g., Landsat-type images or finer), which were only available at high costs and not for smaller domains (Sonnenschein et al., 2011). Today though, the entire USGS Landsat dataset has been available to the public, opening great opportunities for developing the mapping of dryland areas. The choice of vegetation estimate for measuring progressive alterations in drylands using time series of images and vegetation indices has not been agreed by the scientific community (Paudel and Andersen, 2010; Wallace et al., 2004; Washington-Allen et al., 2006), however different indeces may exhibit important variations. Vegetated land is a special type of surface where various physical, biogeochemical, physiological and meteorological processes and interactions between them determine the functioning of terrestrial ecosystems. The spectral reflectance of vegetation in the optical range is determined by the inner structure of the leaves. The chlorophyll content of plants is responsible for the absorption of blue and red light (as can be seen in Figure 1, the reflectance curve for grassland) so that vegetation appears green to the human eye. These absorption capabilities of vegetation are missing in the NIR (Daliakopoulos et al., 2009), therefore, plants show high reflectance in this part of the electromagnetic spectrum.

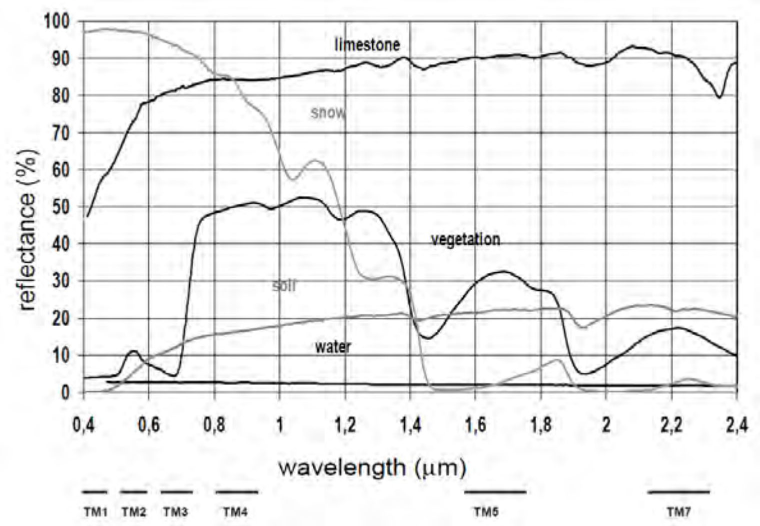



**Figure 1: Typical spectral reflectance curves of different earth surface objects (taken from spectral libraries supplied by NASA) and bands (TM1 to TM7) covered by Landsat TM sensor.**

Pearson and Miller (1972) are pioneers in the history of vegetation indices. They developed the first, two indices in the form of ratios: the "Ratio Vegetation Index" (RVI) and the "Vegetation Index Number" (VIN), for the estimation and monitoring of vegetative covers (Bannari et al., 1995). Two decades later, over forty vegetation indices had been developed in order to enhance vegetation response and minimize the effects of soil brightness, environmental effects, shadow, soil color and moisture, etc. (Bannari et al., 1995). Today, Henrich et al. (2012) list 261 indices relevant to vegetation that can be derived using data from 99 different satellite sensors. The NDVI (Deering and Haas, 1980) is probably one of the most popular RS indexes and was developed to monitor vegetation conditions over the growing season in the framework of food security programs. The NDVI is a useful and practical way to represent the level or intensity of vegetation activity. It is based on a simple ratio between the near infrared and red spectral bands, which characterize respectively the photosynthesis (red band) and the leaves development (NIR). In fact, there are many different non-parametric vegetation indices, i.e. indices that can be estimated directly from the satellite image, as shown in Appendix I.

## 1.5 Scope and Methods

CASCADE addresses catastrophic shifts in the Mediterranean dryland ecosystems and strives to understand their causes and characteristics. CASCADE looks at 6 Study Sites in southern Europe where ecosystem shifts have occurred or are likely to occur. This report presents essential information about the status and historical evolution of the Study Sites. As such, the focus of the tasks included herein is given to the collection and organization of background information that will frame the context and problems faced in each Study Site. Based on this information, meaningful and integrated descriptions have been compiled for use throughout the project. This historical evolution is relevant with various CASCADE Work Packages and a staple for the critical evaluation of drivers of change in drylands. It is on this information that subsequent work can be based in order to offer new insight and argument on the role of thresholds and tipping points in the land degradation process.

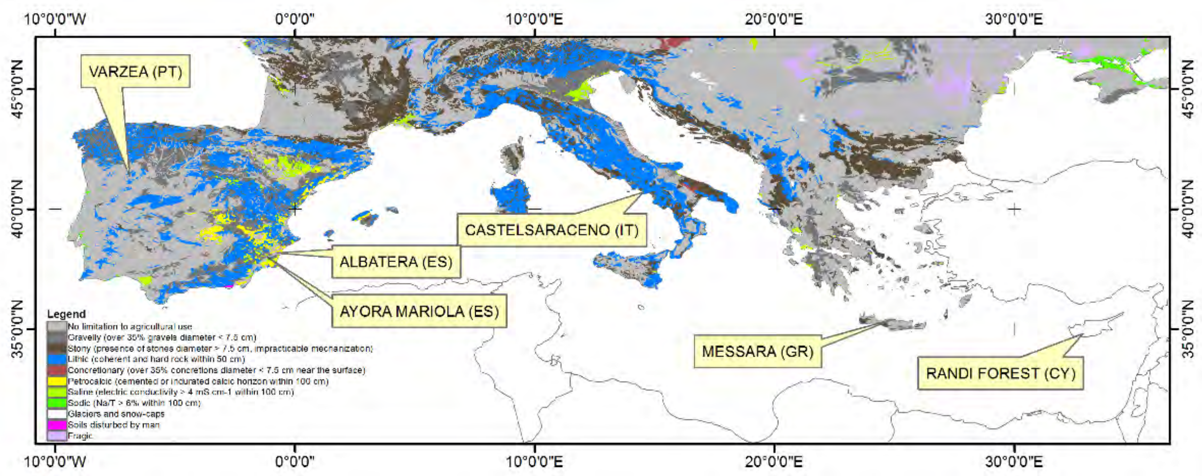



**Figure 2: The CASCADE Study Sites.**

### 1.5.1 Expert knowledge, existing literature and background datasets

Knowledge available at the institutes that coordinate the research in the different Study Sites was used as much as possible. This knowledge includes both expert knowledge, and knowledge about the study sites that is available in papers, reports, databases, etc. to which the coordinating institute has access. To make sure that similar information was provided for all study sites, a template was provided to the study site coordinators. This template contained headings for the different sections in the study site chapters. For each study site, general information including topography, geology and soils, land use, climate and water quality, is provided. A brief description of the main flora and fauna of each site is followed by specific information on the soil-vegetation pair that will be investigated throughout CASCADE experiments, offering a comprehensive picture of each ecosystem. Finally, the socioeconomic status and potential causes of land degradation are discussed for each study site. The general form of the template, denoted as “Data Availability Questionnaire” is included in Appendix II.

The background information established through this process provided a common denominator of available data for all study sites. This data includes study site boundaries in the form of shape files, climate variable time series in the form of spreadsheets, topography in the form of arcgrid DEMs as well as land use, geology and soil shape files. Relevant information was collected and uploaded to a cloud storage system thought which it is now freely shared within the consortium. In addition to background information, all derived products and indices were also made available to all projects partners. This ensures the use of harmonized and quality controlled datasets among WPs that may require them at different points in the lifetime of the project and also minimized overlapping requests to the study sites. Due to storage size limitations, RS imagery that has been collected for the purposes of CASCADE is available to partners only upon request.

### 1.5.2 Remote sensing data

There have been manifold approaches to analyze dryland conditions with satellite RS data. A majority of applications focuses on spectral indices to link properties of rangeland vegetation with RS based assessments (Anderson et al., 1993; Foran, 1987; Graetz and Gentle, 1982; Graetz et al., 1988; Leprieur et al., 2000; Moleele et al., 2001; Todd et al., 1998). Others have successfully linked RS based assessments of grazing patterns with grazing models for trend analysis and pattern forecasting (Pickup et al., 1998; Pickup and Chewings, 1988). Other studies have focused on long-term monitoring of vegetation change, land degradation assessments or desertification monitoring efforts (e.g. Seixas, 2000; Trefois, 1995).

Vegetation units have traditionally been extracted through visual interpretation and manual digitizing of large scale aerial photographs (Dralle and Rudemo, 1997; Larsen and Rudemo, 1998). This technique, although efficient for detailed mapping, is time consuming and may be largely impractical (Mathieu et al., 2007). Until recently, the spatial resolution of satellite sensors has been too coarse (e.g. 30 m or 20 m for Landsat or SPOT) to be appropriate for application, given the size of a tree crown. The automatic extraction of features like tree crowns from VHR images requires validation in the field which is time consuming and ineffective for large areas. The problem of tree counting and classification can also be solved using a physical method. This alternative would involve a statistical model that can estimate the population size based on random and non-uniform sampling. This technique is expected to produce a low resolution result that might not be useful for precision agriculture and water management. Another alternative is a physical survey which has low efficiency and is highly dependable on time variability. Furthermore, ground truthing depends on logistics much more than for other observations, mainly because of the scale of the data.

Long term, global dataset values at 2.5° resolution (Pinzon et al., 2005; Tucker et al., 2005) can also be used to get an approximate idea of the NDVI fluctuation in a selected area. In order to provide an overview of the NDVI behaviour at the landscape level, here we use global values that are corrected for bias using data extracted from selected quality controlled Landsat images. The process followed to extract vegetation indices from Landsat imagery can be summarized in the following steps:

1. Reclassification of zero values: Satellite imagery is reclassified to depict zero values as “no data” so that vegetation indices are not estimated for areas where no data is available. For this step the ARCGIS Reclassify tool can be used.

2. Normalization: Landsat 7 ETM+ and Landsat 4-5TM cannot be directly compared due to different sensor calibration and therefore before processing all images need to be normalized to a common format. This procedure is described by Vogelmann et al. (2001).

3. Transformation of Digital Numbers (DN) to radiance: Raster Calculator can be used to transform Landsat 7 ETM digital values to radiance using a procedure described by Chander et al. (2009) for each band.

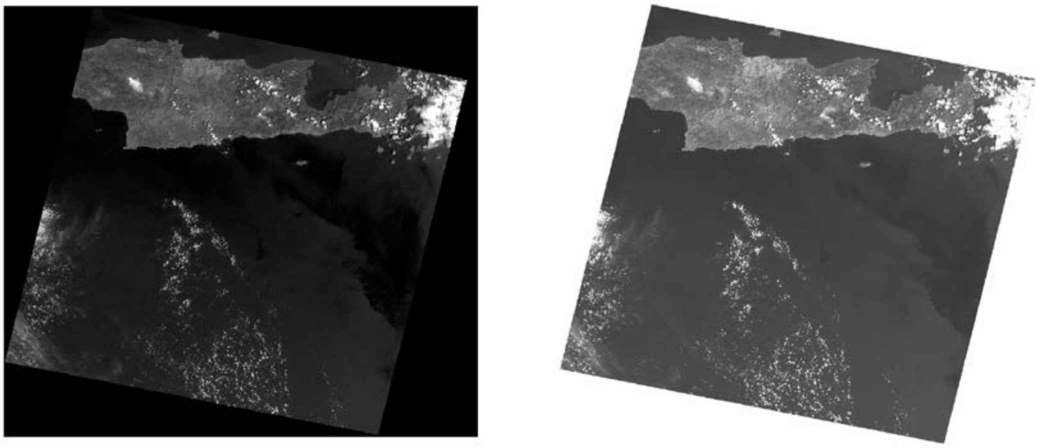


**Figure 3: Initial Lansat 5 TM DN image (left) and reclassified image (right).**

4. Transformation of radiance to reflectance: While sensors measure radiance, all estimation and comparisons have to be made in reflectance values that take into account the position of the sun and other distortions. The procedure (Chander et al., 2009) requires the use of variables included in the *_MTL.txt files that are part of the satellite image header file.

5. Negative values: In the process of transforming DN values to reflectivity, some negative values may occur. These values are set equal to zero using Raster Calculator.

6. Index estimation: For each of the available indexes (e.g. Appendix I) Raster Calculator can be used to estimate the value from reflectivity values estimated above.

7. Statistics calculation: For the calculation of NDVI statistics for a selected area, the shapefile of the area of interest is used with the ArcGIS Zonal Statistics tool. The mean and standard deviation values for the area covered by the shapefile are used as representative of the NDVI in the selected area (Figure 4).

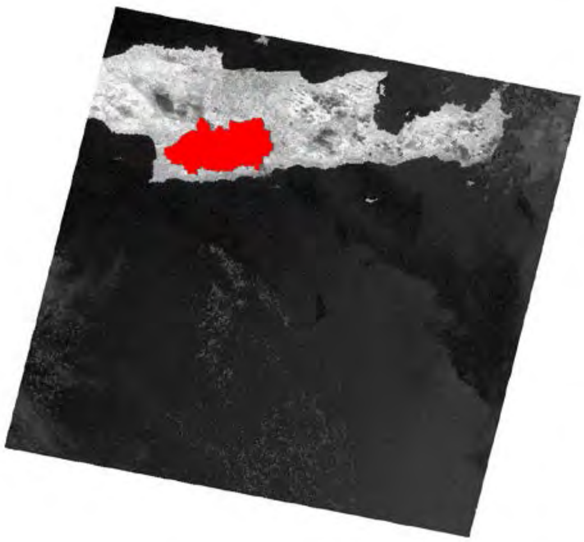


**Figure 4: Area of interest over the satellite image.**

The entire process can be passed in an ArcGIS Perl script that can perform the above steps in batch mode.

### 1.5.3 Climate data

Climate data were provided by the Study Site coordinators. WP2 analysed the data for all 6 Study Sites using exactly the same procedures. Monthly precipitation and monthly mean temperature were plotted to determine if there was any trend in these over the time. For both temperature and rainfall, data series covering the period 1960-2012 were used.

The Standardised Precipiation Index (SPI), developed by MacKee et al. (1993) was also calculated for all sites, to assess the occurrence of droughts and to look for trends in the occurrence of droughts. The index offers the capability to assess drought conditions over a wide range of time scales, while comparison between dry and wet periods on different locations is facilitated. Moreover, it is based on precipitation alone, so that a drought could be assessed even when other hydro-meteorological data are not available (Bonaccorso et al. 2003). In its original version, precipitation for a long period at a station is fitted to a Gamma probability distribution, which is then required to be transformed into a normal distribution so that the mean SPI value is zero. The index values are then the standardized deviations of the transformed precipitation totals from the mean. The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \text{ for } x > 0$$

where $a$ is a positive shape parameter, $\beta$ is a positive scale parameter, $x$ is the precipitation amount, and $\Gamma(a)$ is the gamma function. Positive SPI values indicate wet conditions, with rainfall above median precipitation, whereas negative values indicate dry conditions with less than median precipitation. SPI can be calculated for various time periods (see e.g. McKee et al., 1993; Labedzki, 2007). Periods with drought conditions are represented by relatively high negative deviations. Specifically, the “drought” part of the SPI range is arbitrary divided in four categories, as shown in Table 1. A drought event is considered to start when SPI reaches negative values and ends when SPI becomes positive again (McKee et al., 1993). There is a general agreement about the fact that the SPI computed on shorter time scales (3 or 6 months) describes drought events that affect agricultural practices, while on the longer ones (12, 24, or 48 months), the effects of a precipitation deficit on different water resource components are given (soil moisture, stream flow, groundwater and reservoir storage). Here we use a 48 month period to remove short lasting droughts from the time series, and to focus on droughts with longer durations as these are potentially more harmful to the ecosystems in the Study Sites.

Finally, the annual Aridity Index (AI) is calculated for all sites to assess whether trends in aridity in the Mediterranean region do exist. Aridity can be defined in general terms as the dryness of the climate and numerical indicators can help assess its magnitude at a given location. The concept of climate classification was developed at the early 20th century by Wladimir Köppen and Rudolf Geiger. Their classification approach was based on annual precipitation and temperature records, reflecting the effects of the thermal regime and the amount and distribution of precipitation in determining the native vegetation potential in an area. Later, Thornthwaite (1948) proposed an aridity index based on precipitation and potential evapotranspiration. In 1992, UNEP (1992) adopted the Aridity Index $AI_U$ defined as the ratio of annual precipitation and annual potential evapotranspiration. This index was also adopted by the United Nations Convention to Combat Desertification - UNCCD (UN, 1994) to define arid, semi-arid and dry sub-humid areas. The European Environment Agency (EEA) adopted the UNEP Aridity Index to obtain insight into the problems associated with water resources in the semi-arid areas of Europe, using the potential evapotranspiration according to Penman's (1948) formula. The $AI_U$ Aridity Index is also used here to form an initial characterization of the dryland ecosystems that can potentially be vulnerable to desertification. The regimes identified by different values of $AI_U$ are shown in Table 2. Gao and Giorgi (2008) have also used the UNEP Aridity Index to estimate the possible effects of late 21st century climate change on the Mediterranean region under increased greenhouse gas concentrations.

**Table 1: Thresholds of the SPI for drought characterization.**

| SPI Value | Category |
|---|---|
| 2 or more | Extremely wet |
| 1.5 to 1.99 | Severely wet |
| 1.0 to 1.49 | Moderately wet |
| 0 to 0.99 | Mildly wet |
| 0 to -0.99 | Mildly dry |
| -1 to -.1.49 | Moderately dry |
| -1.5 to -1.99 | Severely dry |
| -2.0 to less | Extremely dry |

**Table 2: UNEP Aridity Index classification.**

| Classification | Aridity Index |
|---|---|
| Hyperarid | $AI_U < 0.05$ |
| Arid | $0.05 < AI_U < 0.20$ |
| Semi-arid | $0.20 < AI_U < 0.50$ |
| Dry subhumid | $0.50 < AI_U < 0.65$ |

# 2 Várzea Study Site (PT)

Responsible partner: UAVR (6)

## 2.1 Definition of the Várzea Study Site

### 2.1.1 General information

The Várzea Study Site is located in north-central Portugal (Figure 5), and encompasses an area of some 30 km$^2$, that was burnt by a wildfire during early September 2012, as well as its immediate surroundings (corresponding to the reference, long-unburnt conditions). This 2012-burnt area pertains to seven local administrative units (the so-called "freguesias"), all of which make part of the Viseu municipality as well as Viseu District. Three "freguesias" were clearly most affected by the 2012 wildfire, i.e. Calde, Cepões and Lordosa. The nine plots being studied in WP3 are all located in the Calde freguesia (even though site selection did not explicitly consider the "freguesias").

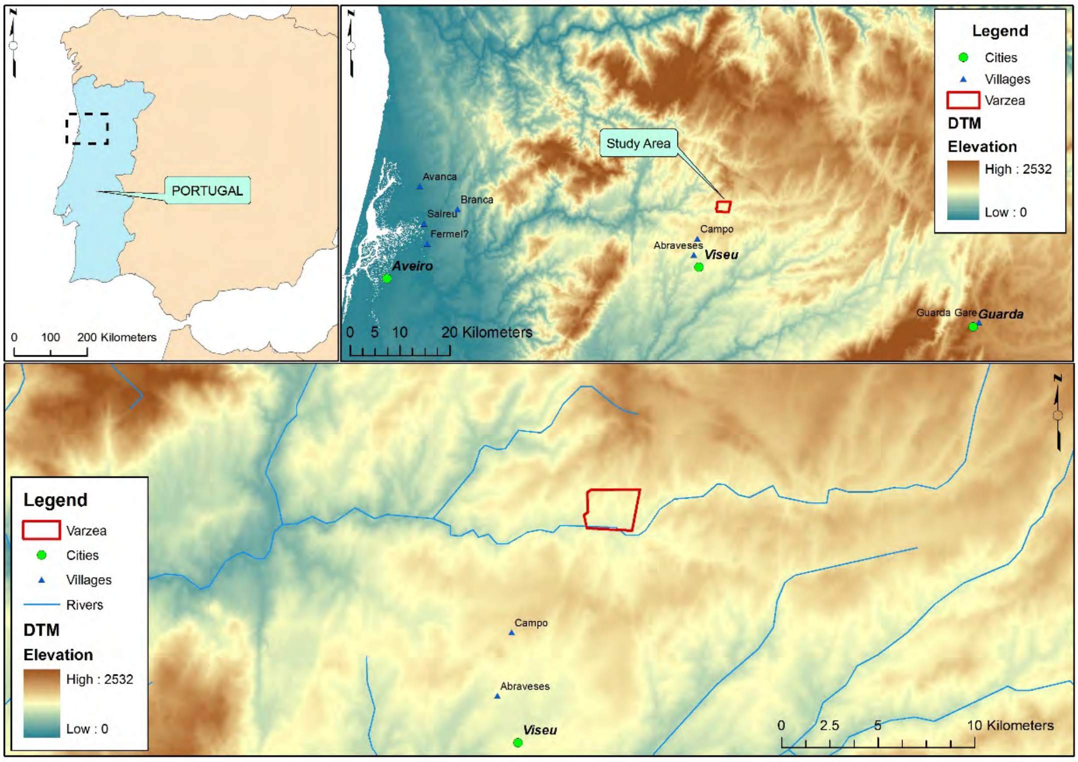



**Figure 5: Study area – Várzea.**

### 2.1.2 Topography

The Várzea Study Site pertains to the major physiographic unit of the Hesperic Massif and, more specifically, to the Central Iberian Zone (Ferreira, 1978). This Study Site is located in the foothills of the Montemuro mountain complex, at elevations between 450 and 600 m (Figure 5). The site is dissected by a series of small watersheds that have an overall south(-western) drainage direction, towards the Vouga river, and, thus, are headwater catchments of the regional-scale Vouga River Basin. The Vouga river itself is restricted to Portuguese territory, has a total length of 136 km and drains a total area of

3.700 km$^2$ (Ribeiro et al., 1997), finally discharging into the coastal lagoon area of the Ria de Aveiro. The Vouga river is an important source of drinking water for its downstream municipalities, through the Carvoeiro water capture station, and will be an important source of hydric energy, through the Ribeiradio-Ermida dam complex that is currently under construction.

### 2.1.3 Geology and Soils

As part of the Hesperic Massif, the Várzea study area and surroundings are dominated by pre-Ordovician schists and greywackes, and Hercynian granites (Ferreira, 1978; Pereira and FitzPatrick, 1995). The nine plots being studied in WP3 are, according to in-situ field observations, underlain by schists or, most probably, greywackes, rather than granites. The soils of the Várzea Study site are mapped, in the JRC WRB Soil Geographical Database, as predominantly Cambisols (excerpt shown in Figure 6). According to the same source, the soils of the Study site principally consist of mollic soil material (Figure 7).

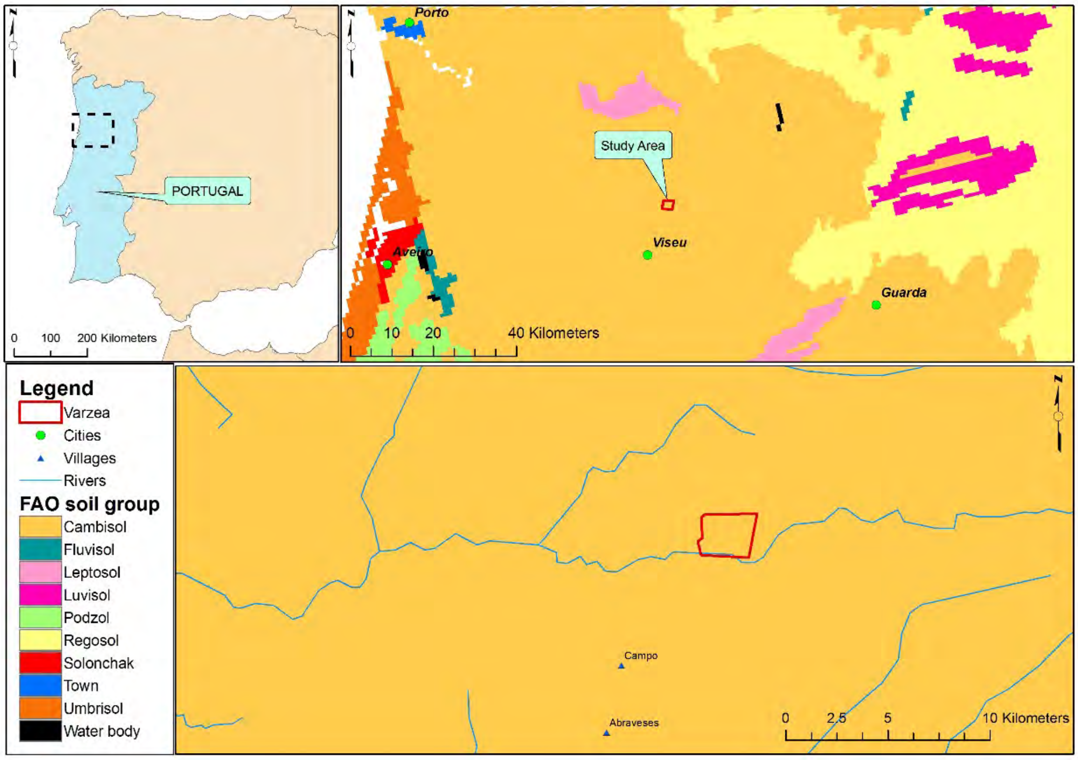



**Figure 6: Soil groups according to the FAO classification in the Study Site (Source: JRC).**

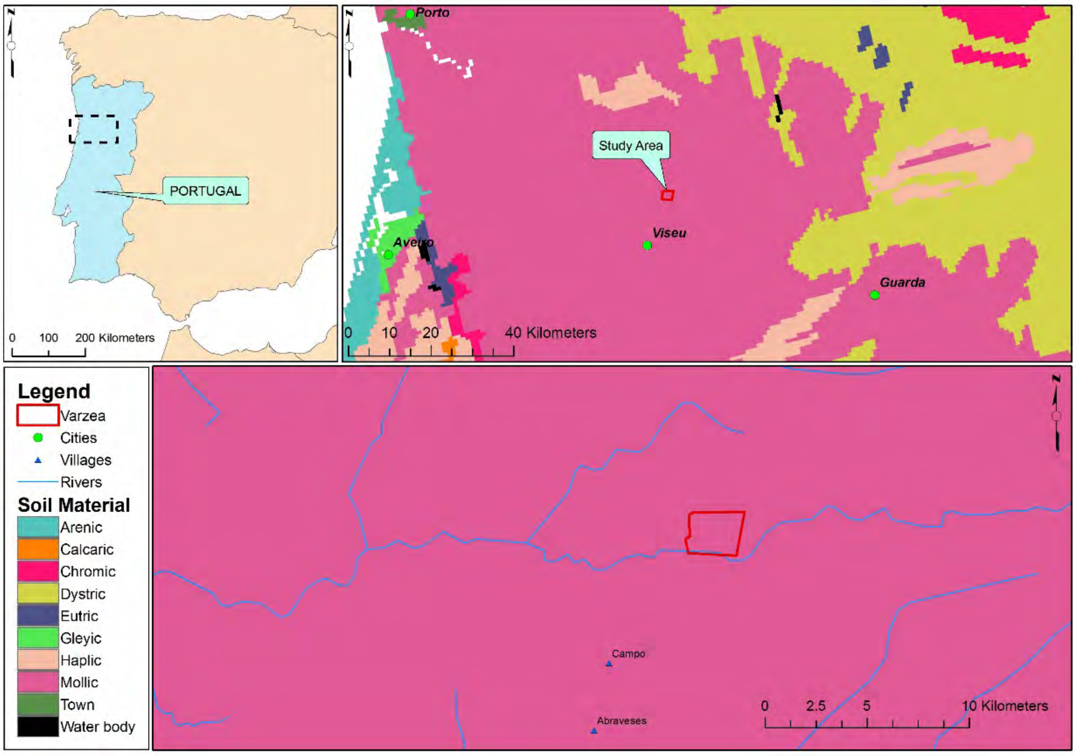



**Figure 7: Categories of Soil Materials (WRB) in the Study Site (Source: JRC).**

### 2.1.4 Land Use

The CORINE database for 1990, 2000 and 2006 shows that, in terms of main land-cover classes, the Várzea Study Site is and has been comparable to the surrounding region, and, as such, representative for large parts of the interior of north-central Portugal (Figure 8). During the last two decades, the predominant land-cover types of the Várzea Study Site have been forests and shrublands (actually “shrublands and/or herbaceous vegetation associations”, but abbreviated here and underneath for reasons of convenience), and to a lesser extent, heterogeneous agricultural areas. These agricultural areas revealed little to no changes between 1990 and 2006, whereas this same period exhibited noticeable transitions between forest and shrubland. These transitions corresponded to a change from shrublands to forests between 1990 and 2000, and to a change from forest to shrublands between 2000 and 2006. Wildfires, in 1985 and again in 2005 (with burnt areas of roughly 10 and 1 $km^2$, respectively) are probably the reason behind these transitions, but this is going to be analysed more thoroughly using the NDVI data compiled for the Várzea Study site (see 2.1.6). The forests in the Study site consist (and have consisted) predominantly of mono-specific stands of Maritime Pine (*Pinus pinaster* Ait.). Although Maritime Pine is a (western) Mediterranean species (Ribeiro et al., 1997), its present-day widespread occurrence in the Study Site is, as in the rest of Portugal, owed to planting and, thus, human activities. In the wider study region, extensive planting of public forest with Maritime Pine took place during the late 1940s and early 1950s in particular (Rego, 2001).

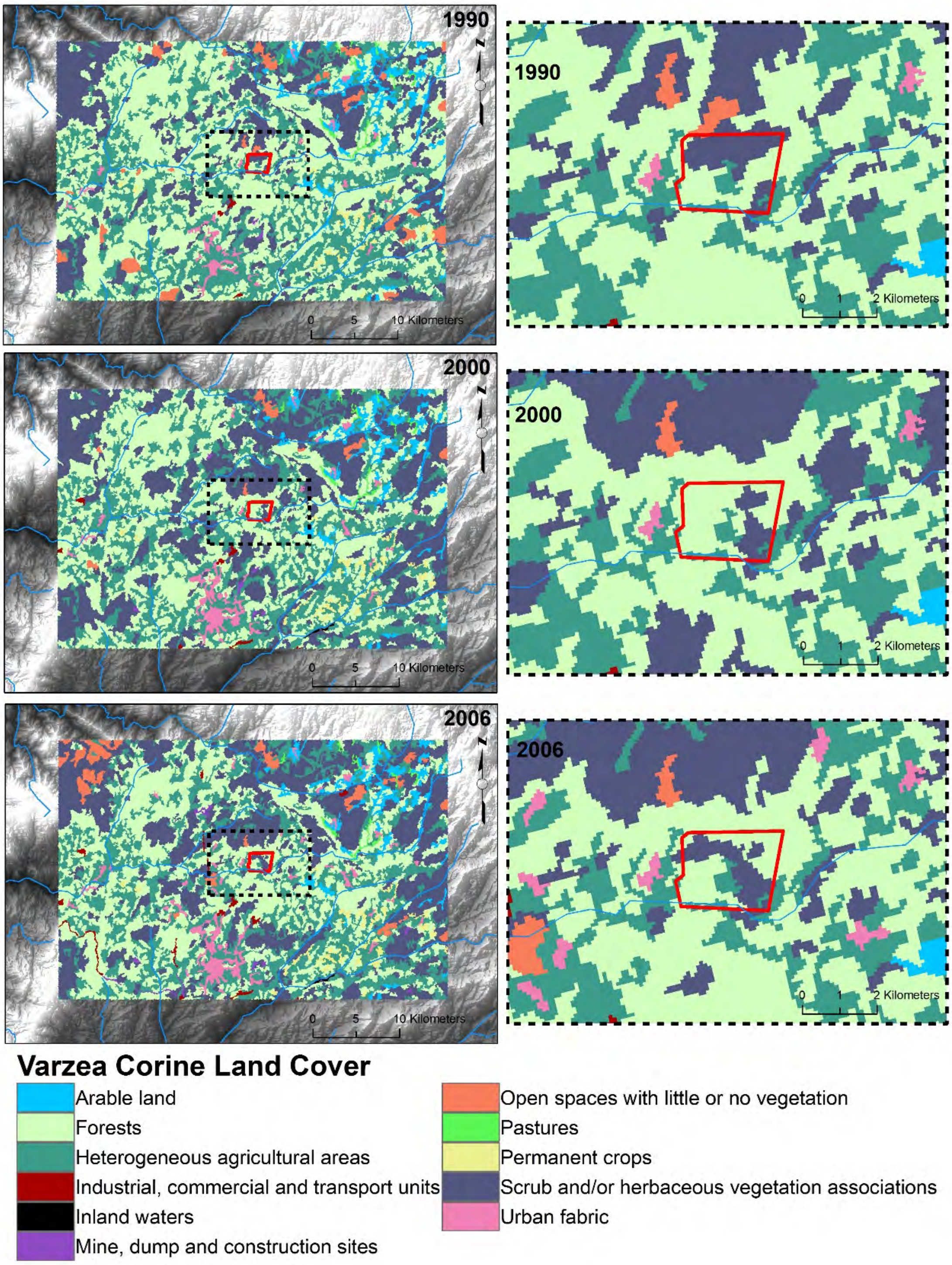



**Figure 8: Land use in the Study Site (Source: CORINE, JRC).**

### 2.1.5 Climate

The climate of the Várzea Study site can be classified, according to Köppen's system, as humid meso-thermal with a prolonged dry and warm summer (i.e. Csb; DRA-Centro, 1998). It is during these dry and warm summers that the majority of wildfires occur. Rainfall varies strongly, not only seasonally but also inter-annually, as is typical for Mediterranean-type climate regions. At the nearest rainfall station to the Várzea Study Site, at some 11 km distance (Sátão: 40.74 $^{o}$N, -7.74 $^{o}$W, 570 m), annual rainfall during the period 1960-2009 varied between 550 and 2080 mm, and amounted, on average, to 1170 mm. The monthly rainfall at the Sátão station during this period is shown in Figure 9, illustrating well the sometimes very intensive nature of rainfall in the study region. Monthly rainfall exceeded 500 mm at four occasions and two of these four occasions occurred only four months apart (December 2000 and March 2001). Moreover, air temperature reveals a pronounced seasonal variation (Figure 10). At the nearest climate station to the Várzea Study Site, at some 13 km distance (Viseu: 40.72 °N, -7.88 °W, 644 m), mean monthly temperatures during the period 1960-2009 ranged from 6.3 °C in January to 20.5 °C in July, whereas minimum and maximum monthly temperatures during this same period were 3.1 °C (December 1967) and 25.5 °C (July 1989). There is a noticeable trend in this time series with respect to the lower values. Monthly temperatures below 4 °C occurred in a total of 10 instances until January 1973 and, thus, exclusively during the first 13 of the 30 years on record.

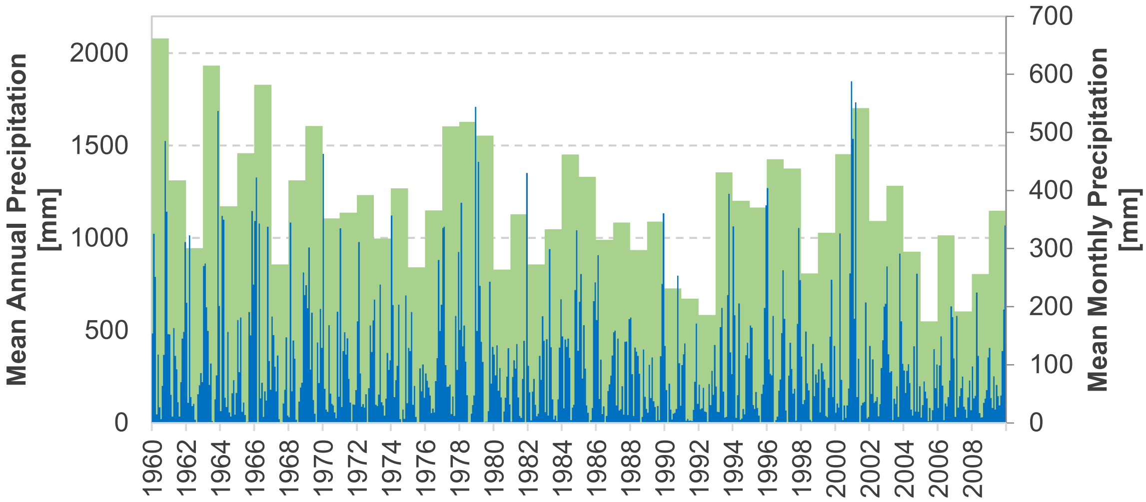



**Figure 9: Monthly (blue) and annual (green) precipitation at the nearby Sátão rainfall station.**

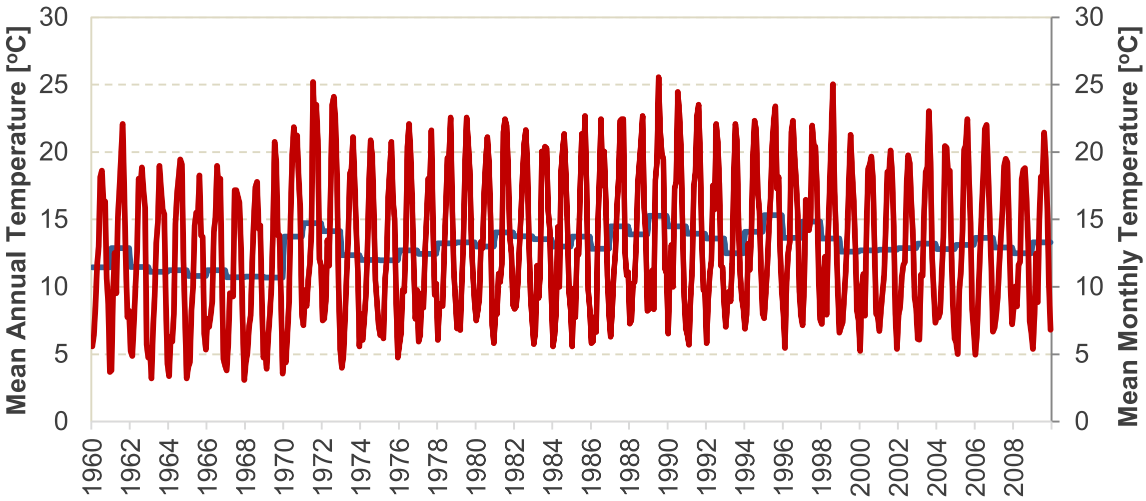



**Figure 10: Mean monthly (red) and annual (blue) temperature at the nearby Viseu climate station.**

### 2.1.6 Main Ecosystems

***Flora***

No floristic data are available specifically for the Várzea Study Site or its immediate surroundings. Field observations, however, suggest that the understory of the nine Maritime Pine stands being studied in WP3 bears a marked resemblance with that described by Maia et al. (2012). The principal plant species include: (a) the shrubs *Erica australis* L., *Calluna vulgaris* (l.) Hull and *Pterospartum tridentatum* (L.) Willk (b) the herbs *Scilla monophyllos* Link and *Simethis mattiazzi* (Vandelli) Sacc and (c) the grass Agrostis curtisii Kerguélen. A synoptic view about vegetation health and the associated function of ecosystems can be derived from analysis of archival and on-going sequences of NDVI. Figure 11 depicts NDVI change through time (green line using datasets from Pinzon et al., 2005; Tucker et al., 2005). NDVI in the study area shows a small rising trend since the 1980s. At the scales examined up to this point, there is no apparent correlation between the fire insidents of 1985 and 2005 with the behaviour of NDVI. The connection of NDVI with individual fire events will be further investigated within the scope of CASCADE project with the use of finer-scale infromation.

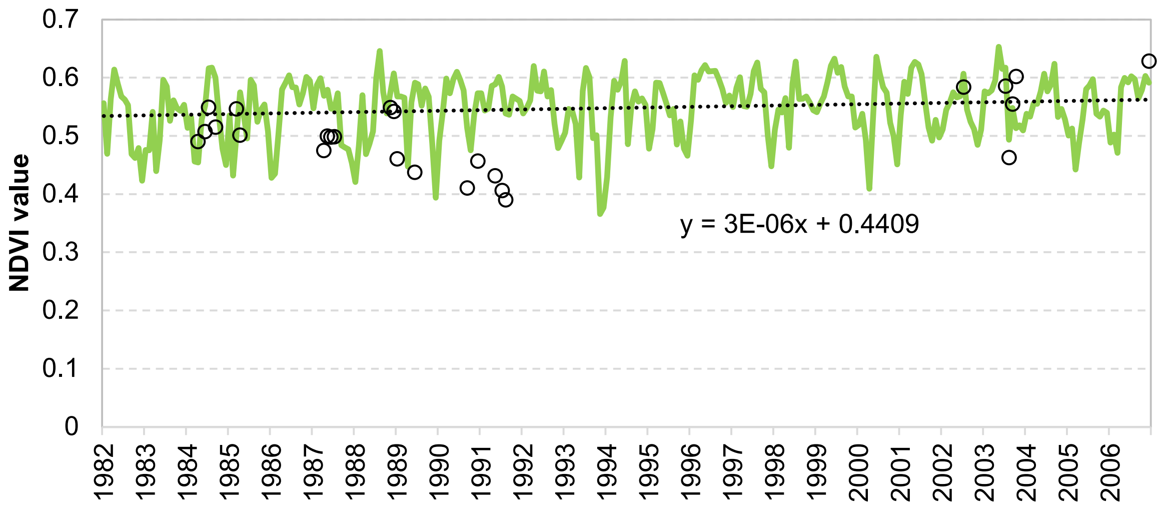



**Figure 11: Historical evolution of NDVI through time (green) corrected for bias using value from LandSat 4-5 imagery (black circles).**

***Selected Vegetation – soil system***

The vegetation-soil system selected in the Várzea Study Site, includes forest stands exclusively or predominantly composed of Maritime Pine trees (*Pinus pinaster* Ait.). They pertain to the sub-spontaneous vegetation association of *Pinetum pinastri* (Ribeiro et al., 1997). The Maritime Pine trees at the nine plots being studied in WP3 were planted and/or seeded (but without apparent evidence of mechanical ground operations), or resulted from spontaneous re-sprouting following wildfire, possibly in combination with thinning activities. The understory vegetation at the nine WP3 plots appears to be spontaneous, albeit their floristic and especially structural composition probably reflects the presence and frequency of land-use practices such as fuel load removal and, more sporadically, goat grazing.

The soils of the nine WP3 plots are all shallow, less than 40 cm deep, and derived from schists or, most probably, greywackes. Soil pits dug out at these plots revealed profiles comprising A and B and/or BC soil horizons, together with a considerable litter layer (7-8 cm thick) in the case of the long unburnt plots. Results of soil texture analysis are still pending at the time of this report so soil profiles have not yet been formally classified. However, field classification points towards a mixture of umbric Leptosols, epileptic Umbrisols and humic Cambisols (WRB, 2006). Field assessment of the soil texture itself suggests a clear predominance of sandy loam soils.

### 2.1.7 Socioeconomic status

In line with the general background of population exodus from the rural inlands of Portugal (e.g. Daveau, 1998), the three "freguesias" most affected by the 2012-wildfire (see 2.1.1) saw their resident populations decrease considerably over the past three decades (Figure 12). The overall decline in population between 1981 and 2011 amounted to 19% in the case of Lordoso, 24% in the case of Cepões, and even 33% in the case of Calde. During these three decades, the decrease was highest between 1981 and 1991 (13-23%), and tended to be milder in the subsequent decade (1991-2001: 0-7%). The elevated proportions of elderly people and the considerable levels of analphabetism, amounting to over 10% in 2011 (12-17%) are worth mentioning with respect to the resident populations of the three above-mentioned "freguesias". In terms of employment, agro-forestry land-use activities had become of limited importance in the three above-mentioned "freguesias" by the time of the 2012 wildfire. In 2011, the primary sector employed 10% of the active resident population of Calde, 4% of Cepões, and 2% of Lordoso. The majority of the active resident population was employed by the tertiary sector in all three "freguesias", about 60% in the case of Calde and Cepões and just over 70% in the case of Lordoso.

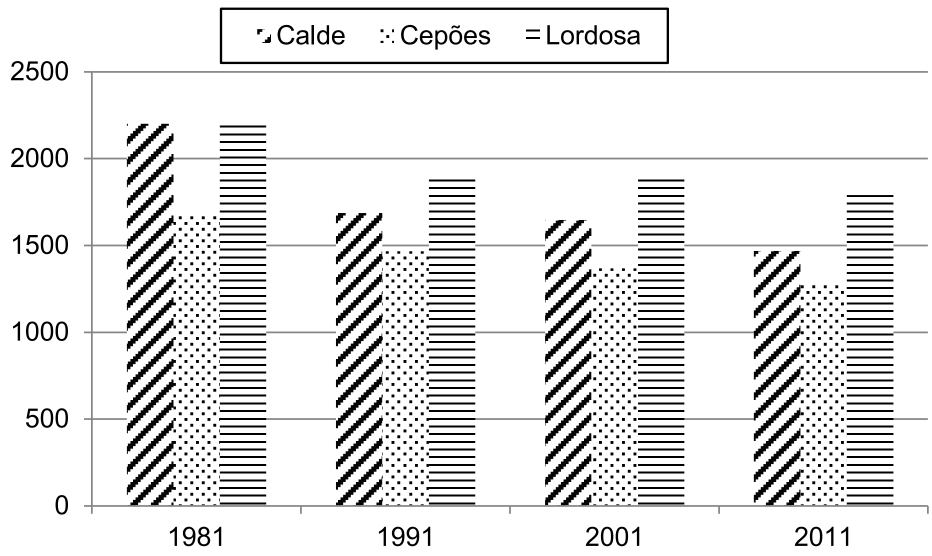



**Figure 12: Evolution of the resident population of the three "freguesias" in the Várzea Study Site that were most affected by the 2012-wildfire.**

### 2.1.8 Timeline of events

In the case of the Várzea Study Site, the timeline of the principal events is relatively straightforward, consisting of the four wildfires that, according to the available burnt-area maps (Pereira et al., 2011), occurred in the area since 1975. These wildfires occurred in 1978, 1985, 2005 and 2012 (pending publication of the official burnt-area map, a field survey of the burnt area was carried out by the UAVR's CASCADE team). According to the information that could be gathered so far, all wildfires occurred during the summer season; the exact dates of the pre-2012 wildfires are still unknown but are needed to characterize the weather conditions prior, during and after these events, thereby getting further insight in fire severity and post-fire vegetation recovery and erosion risk. In terms of the burnt area, however, there are marked differences between the four wildfires, with the ones of 1978 (200 ha) and 2005 (71 ha) being considerably milder than those of 1985 (1067 ha) and especially 2012 (roughly 2700 ha). Figure 13 shows a brief event timeline of the most important changes and milestones that occurred in the natural and social environment of Várzea.

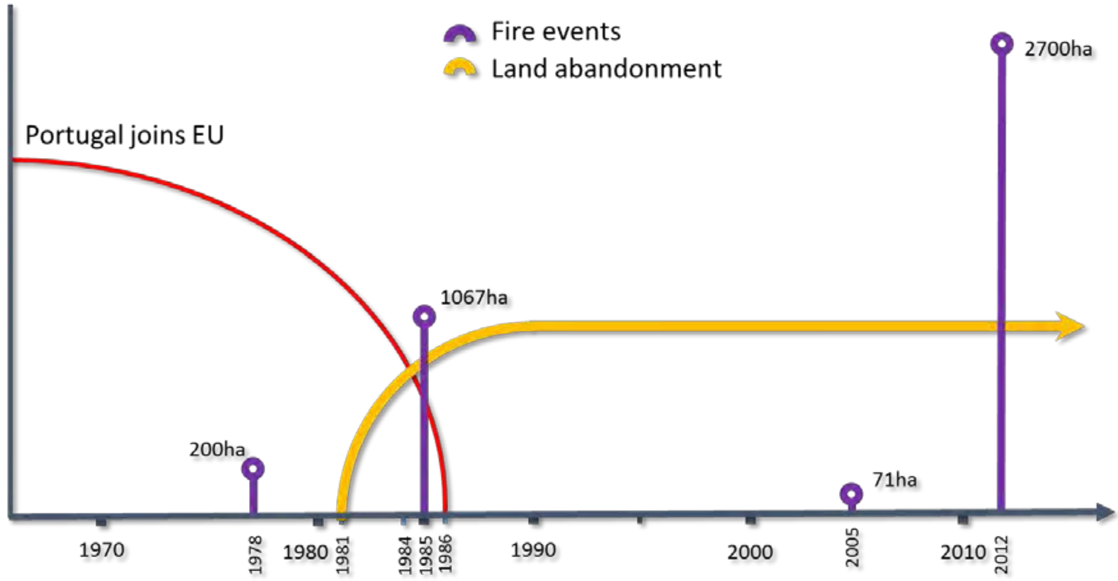



**Figure 13: Event timeline for Várzea since the 1970s.**

## 2.2 Main Causes of Land Degradation

### 2.2.1 Human induced Drivers

The main driver of land degradation in the Várzea study area - forest fires - is regarded as “human-induced”, as the wildfires in Portugal, like in the rest of the Mediterranean basin, appear to be mainly related to human causes (Jappiot et al., 2009). Furthermore, the WOCAT Technologies Questionnaire includes wildfires under the human-induced drivers (“deforestation/removal of natural vegetation (incl. forest fires)”). In the Várzea Study Site, focus is given on the land degradation impacts of the wildfire which occurred in early September 2012. Preliminary assessements show that the effect of this recent event has a different magnitude at plots that had experienced three previous wildfires since 1975 and plots that had been long unburnt for at least 37 years. The possible impacts of the preceding fires will also be analysed, using indicators based on a detailed analysis of weather conditions before and during the fire for assessing fire severity, as well as of weather conditions after the fire. The latter can be combined with NDVI data to assess post-fire vegetation recovery and erosion risk.

### 2.2.2 Natural Drivers

Drought can influence wildfire-induced land degradation through fire characteristics such as ignition probability, fire spread and severity (e.g. Pereira et al., 2005) as well by affecting ecosystem recovery following fire (e.g. Moreno et al., 2011). Long-term drought as indicated by the 48-month SPI was assessed for the Várzea study area for the period from December 1963 to December 2009 (Figure 14). Prolonged spells of comparatively dry conditions (with SPI48 values below -1) could be observed during the early 1990s as well as the late 2000s. Thus, drought could well have played a role in the occurrence and severity of the 2005-fire in the Várzea Study Site as well as in the subsequent recovery of the ecosystem. As also mentioned before, the compiled NDVI data could shed some light on both aspects and the rainfall exclusion experiments of WP3 will be fundamental to improve our knowledge of the role of drought in post-fire recovery of Maritime Pine ecosystems and our understanding of the underlying ecological processes. Drought phenomena in the Várzea Study Site were also assessed using the annual aridity index (Figure 15). This index similarly highlighted that the early 1990s and late 2000s were comparatively dry, with dry sub-humid and even semi-arid conditions in 1992 and 2005.

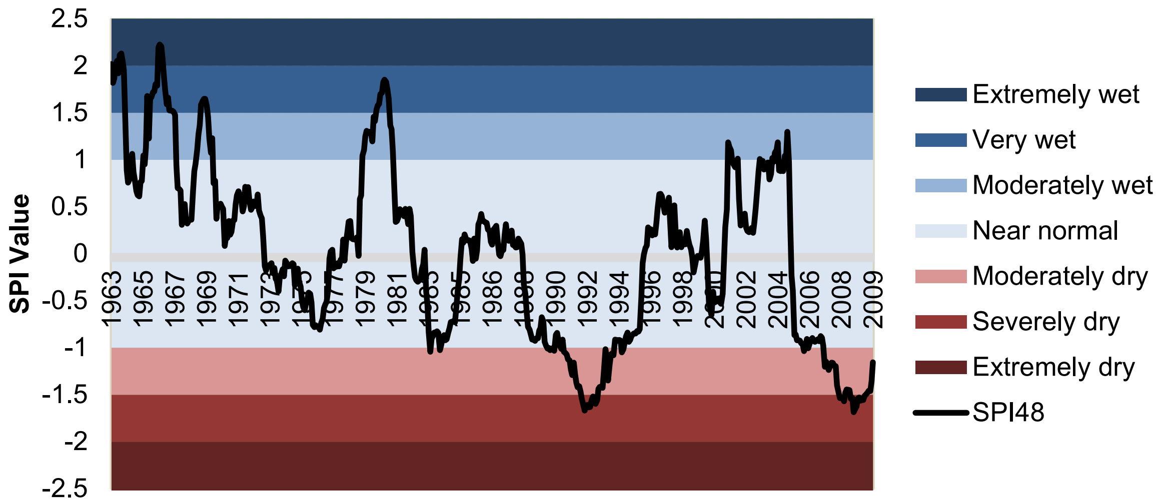



**Figure 14: SPI 48 estimated for the period 1963-2009 for Varzea Study Site.**

Besides drought events, heavy/extreme rainfall can be of crucial importance for the land degradation impacts of wildfires. This especially applies for the initial stages of the so-called “window of disturbance”, when soils are most susceptible to be eroded by water, because their properties still strongly reflect heating-induced changes and continue without a protective cover of litter and vegetation (e.g. Shakesby and Doerr, 2006; Malvar et al., 2011; Shakesby, 2011; Prats et al., 2012).

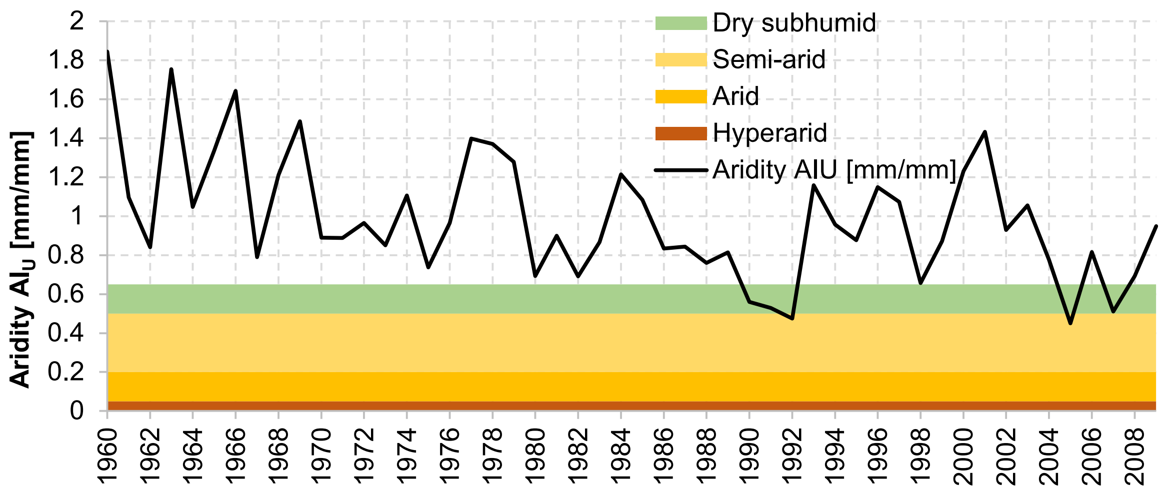



**Figure 15: Aridity estimated for the Varzea Study Site.**

### 2.2.3 Indirect causes

An important indirect cause of land degradation associated to wildfire can be land management. In the wider study region, rip-ploughing in downslope direction in a recently burnt area was found to have increased sediment losses to rates well beyond those immediately after fire (e.g. Shakesby et al., 1996). In addition, post-fire logging can increase soil erosion, especially if it leads to exposure of bare soil (e.g. Fernandez et al., 2007). On the other hand, post-fire emergency treatments, such as mulching, that can effectively reduce soil losses in recently burnt areas (e.g. Bautista et al., 1996; Prats et al., 2012) are poorly established in Portugal.

# 3 Albatera Study Site (ES)

Responsible partner: UA (5)

## 3.1 Definition of the Albatera Study Site

### 3.1.1 General information

The Albatera site is located on the Albatera-Crevillente range, within Albatera municipality, in Alicante province, Southeast Spain (Figure 16). An agricultural plain, part of the Segura river valley, lies south of the range and includes the town of Albatera, with a population of almost 12,000 inhabitants. Albatera municipality has mostly remained rural, although a variety of industries (such as textile, construction and mining) are also relevant in the area. The Albatera Study Site for CASCADE comprises a set of areas with natural vegetation (i.e. no croplands) on the southern area of the range (Figure 16).

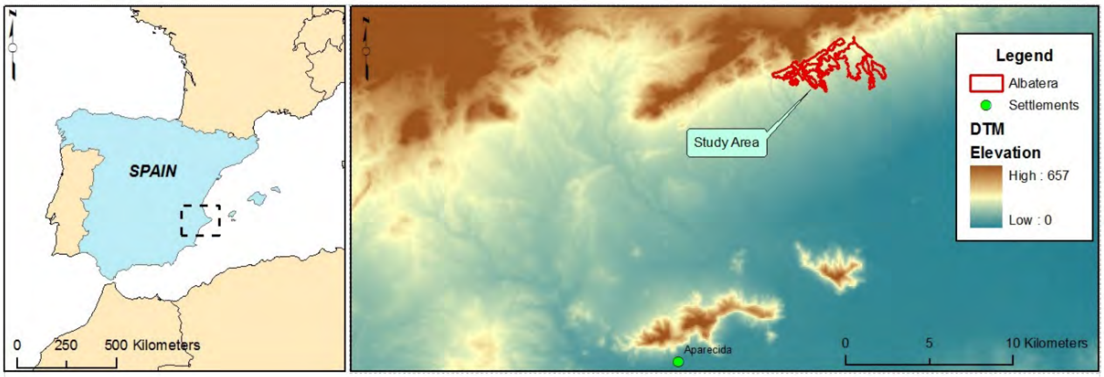



**Figure 16: Study area – Albatera range.**

### 3.1.2 Topography

The Albatera-Crevillente range is located within the easternmost extreme of the Subbetic zone of the Betic Cordilleras, which crosses the South of the Iberian Peninsula at WSW-ENE direction. San Cayetano is the highest peak in the range (816 m) whereas the highest within the Study Site is Monte Alto (682 m). Slopes are moderate, as in 25% of the area slope angle is under 25%. Mountainous areas are fragmented by ravines (ramblas), forming perpendicular to the range, frequently along tectonic faults. The range is connected to the alluvial plain by a relatively narrow strip of intermediate elevation hilly area, where both hillslopes and ravines are deeply altered by crop terraces (Figure 17).

**Figure 17: General view of the western area of Albatera Study Site (Photo: S. Bautista).**

### 3.1.3 Geology and Soils

The range is formed by an anticline of Triassic, Jurassic and Cretaceous materials (gypsiferous loams of Keuper facies, limestones, dolomites, and dolomite limestones), whose WSW-ENE axis dips toward the East below a Miocene series. The Tertiary series begins, discordant, with levels of conglomerate and sandstones (molasses) and continues with loams, clays, marls, poorly-cemented sandstone, and ending with layers of conglomerate, sandstones and loams from the Pliocene. The compact calcareous nature of the core of Jurassic materials contrasts with the Tertiary materials, resulting in marked differential erosion that creates high mountain peaks bordered by deep ravines with vertical walls. According to the JRC WRB Soil Geographical Database, dominant soils in the mountain range area are Calcisols, while dominant soils in the alluvial plain south of the range are Cambisols and Fluvisols (Figure 18). According to the same source, aridic soils are dominant in the mountain range, while calcaric soils are dominant across the alluvial plain (Figure 19).

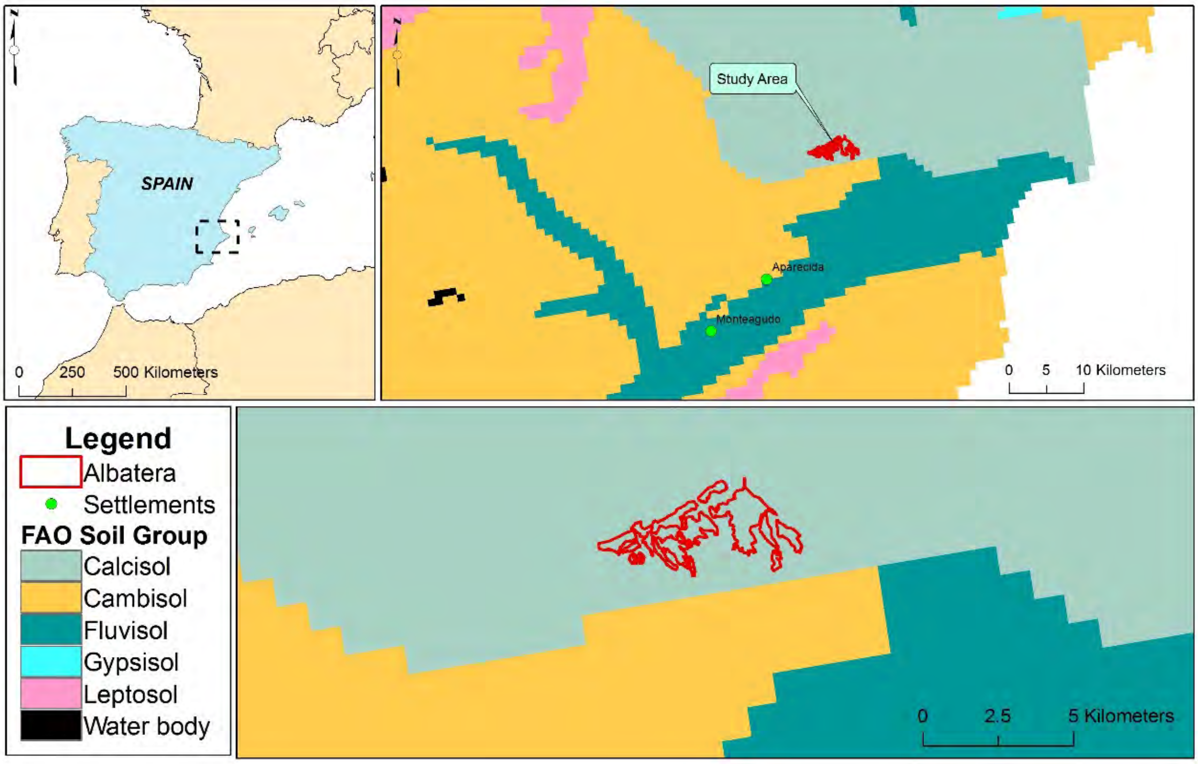



**Figure 18: Soil groups according to the FAO classification in the Study Site (Source: JRC).**

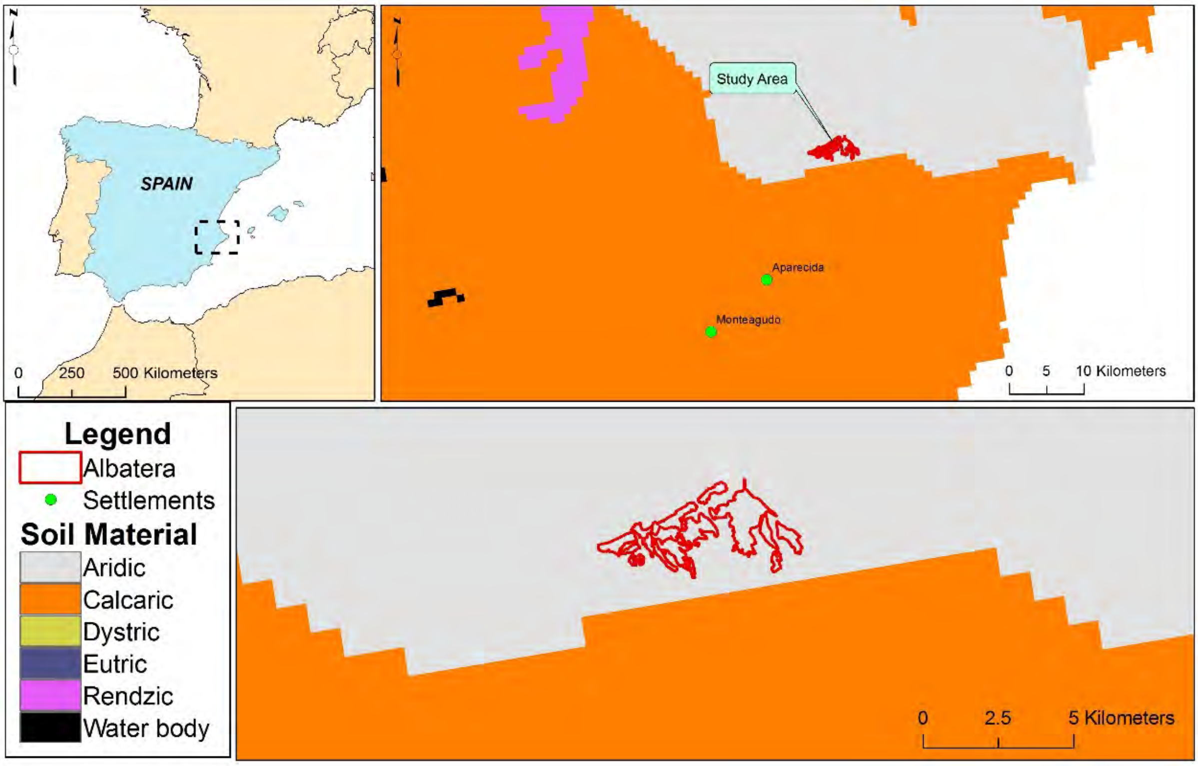



**Figure 19: Categories of Soil Materials (WRB) in the Study Site (Source: JRC).**

### 3.1.4 Land Use

The Albatera municipality has a surface area of 6,639 ha. Main land use in the Albatera area is agriculture (52% of the land) with scrublands and woodlands covering 24% of the area. The rest of the land (21%) is distributed among a variety of land uses, including urbanisation and industries. Crops are distributed as follows; 1/3 of lemon and orange tree crops; 1/3 of fruit-tree crops such as pomegranates and figs and 1/3 of a variety of crops including olive trees, date producing palm trees and vineyards. The Study Site, which is located on the mountain range area, is mostly covered by a mosaic of shrublands and degraded scrublands, with some patches of pine forests that resulted from various reforestation/afforestation activities implemented in the 1970s-80s. CORINE Land Cover data (Figure 20) show no change in the Study Site between 1990 and 2006, which points to a rather stable nature of the woodland-scrubland zones (despite the various reforestation activities in the area). The only significant change was the transformation of several patches of arable land into permanent crops after 1990.

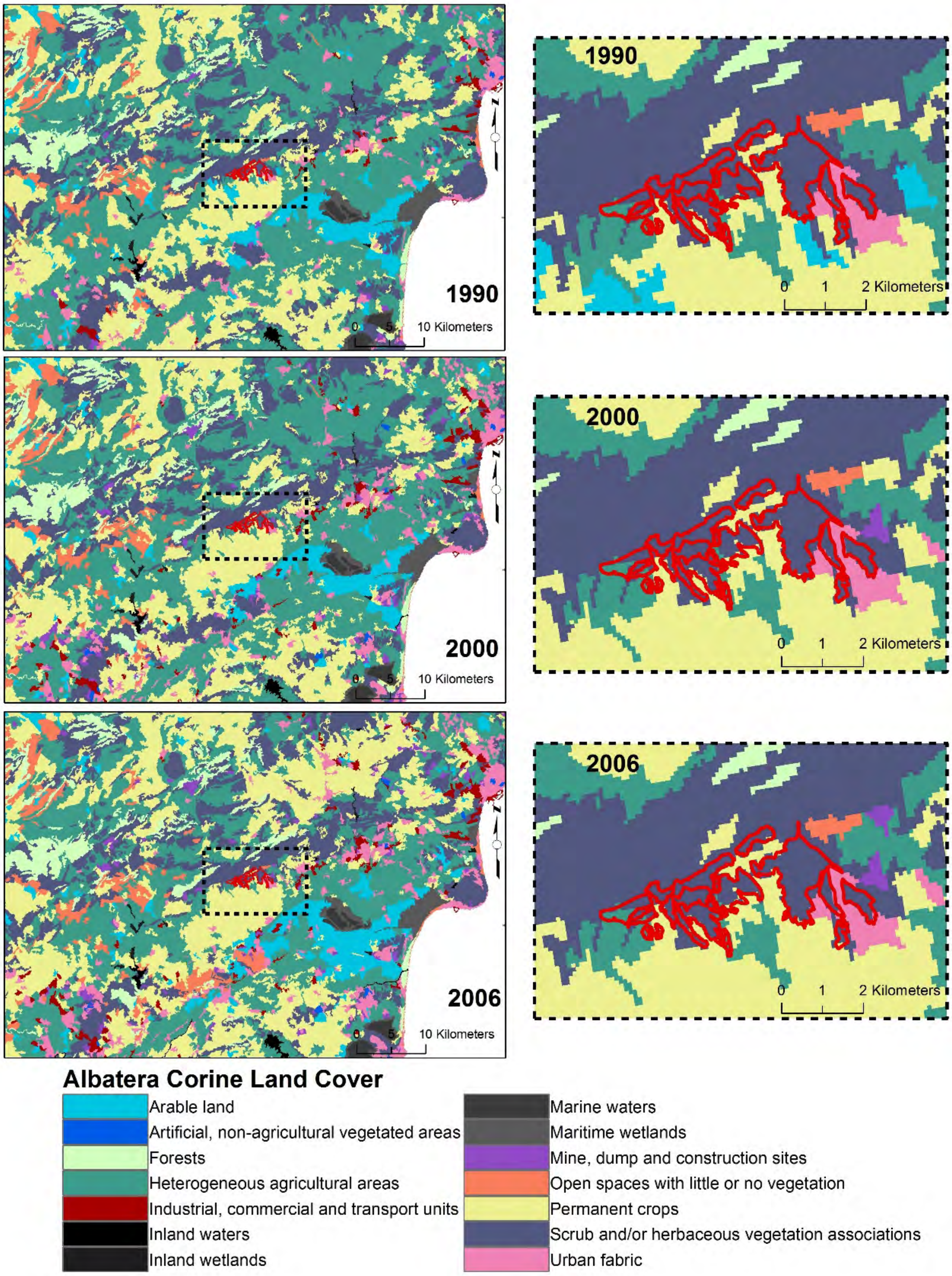



**Figure 20: Land use in the Study Site (Source: CORINE, JRC).**

### 3.1.5 Climate

Albatera climate is classified as (*steppe*) *semiarid* according to the Köppen climate classification, and as *arid* according to the UNEP Aridity Index (AI) adopted by the UNCCD (Middleton and Thomas, 1997). About 35% of the annual precipitation occurs in autumn, 30% in spring, 20% in winter and only around 15% of rainfall during summer

(Pérez-Cueva, 1994). The highest values of monthly precipitation are commonly recorded in October. Figure 21 shows the mean monthly precipitation at Albatera derived from the E-OBS dataset (Haylock et al., 2008). Concerning the available record, precipitation shows no significant trend and remains stable at an annual rate of 267 mm.

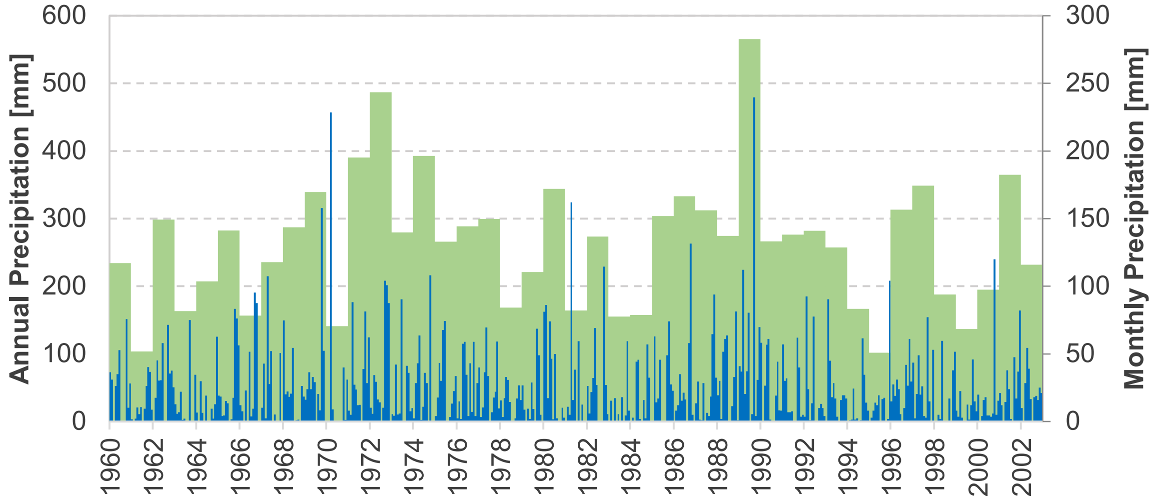



**Figure 21: Monthly (blue) and annual (green) precipitation from the E-OBS dataset.**

Figure 22 shows the mean monthly temperature at the Study Site as it was estimated from the E-OBS dataset (Haylock et al., 2008). For the available record, temperature shows a slight upward trend with an annual mean of 18 $^{o}$C. The potential evaporation for the Study Site was estimated at 1,633 mm using the E-OBS dataset and the Blaney-Criddle equation (Blaney and Criddle, 1962).

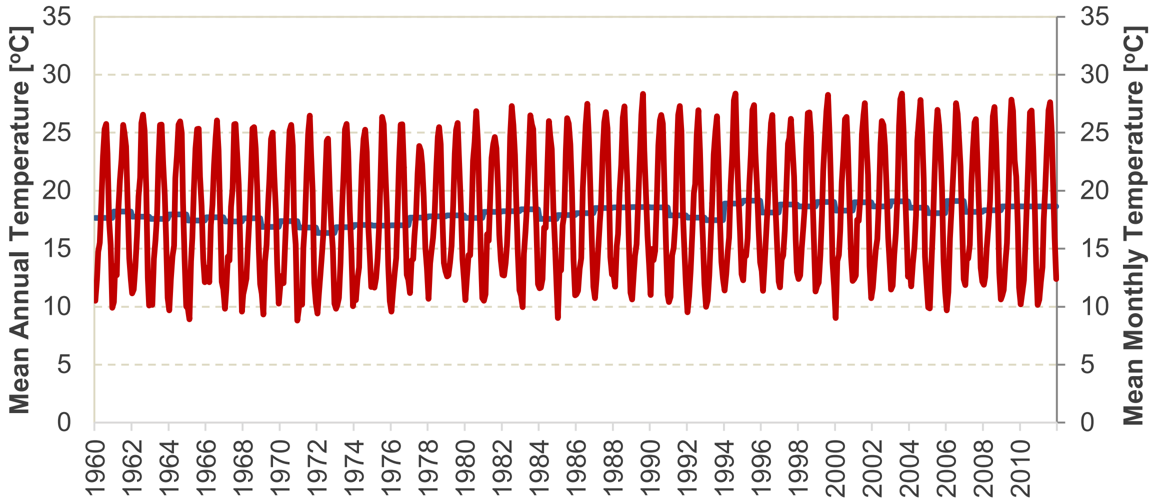


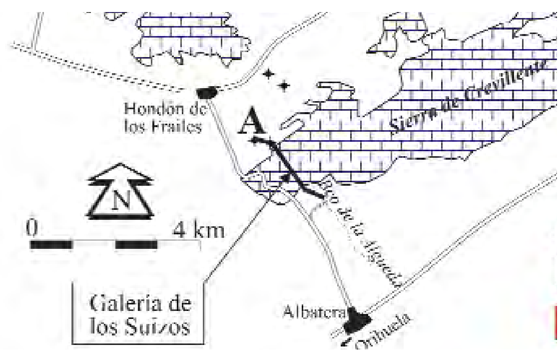

**Figure 22: Mean monthly (red) and annual (blue) temperature at Albatera derived from the E-OBS dataset and corrected for bias.**

### 3.1.6 Hydrogeology

There is no permanent-flow channel in the Albatera area. However, the overland flow produced on the mountain-range slopes concentrates along a number of intermittent-flow channels (*ramblas*) that only carry water after major rainfall events. On their high course, the *ramblas* have a great erosive potential, creating a system of deep channels that connect the mountain range and the lowland. On the lowland, the *ramblas* become wider and shallower, and the channels are often altered by human activities. Finally, the channels disappear into the alluvial plain, where runoff becomes diffuse.

The Albatera area hosts parts of two aquifer systems: The “Vega Baja” and the “Crevillente” aquifers. Both aquifers provide water of relatively poor quality that is mostly used for irrigation. The “Vega Baja” aquifer is a large (750 $km^2$) alluvial aquifer that lies on the south of the area (alluvial plain) and comprises the Quaternary sediments of the low valley of the Segura river. The “Crevillente” aquifer (140 $km^2$), is partly located within the Albatera Study Site. It is a karstic aquifer that comprises a series of Jurassic limestones and dolomites, more than 500 m thick, which forms the core and uppermost part of the Albatera-Crevillente range. The system lacks of streams or springs with permanent flow. Recharge results from effective precipitation over outcrops of permeable rocks, and it has been estimated to range between 6 and 10 $hm^3$ per year, with peaks up to 16 $hm^3$ in very wet years (Andreu et al., 2008).

The southwestern area of Crevillente aquifer (located within the study area) is exploited through the water-mining system of “Los Suizos Gallery” (Figure 23). Inside the gallery, there are wells that pour the extracted water on the gallery floor. Water is driven over 2 km until the gallery mouth, in the southwestern limit of the Albatera-Crevillente range, and distributed for irrigation from this point. Intense exploitation of the aquifer started in the early 1960s, with the construction of the Gallery, and continued over several decades, resulting in a total decrease in piezometric level of around 200 m (Figure 24), abandonment of boreholes, and severe deterioration of water quality. In 1987, the governmental water Authority declared the aquifer as overexploited. Although water extraction has been reduced in recent years, water is still highly mineralised and of very poor quality, and several overexploited pockets can still be identified in the area (Andreu et al. 2002, 2008). Today, out of the original 12 extraction points drilled inside the gallery, only four pumps remain in use, the others having been abandoned. The current pumping capacity is 350 l/s. The water extracted is mainly used to irrigate various areas within the boundaries of Albatera and neighbouring municipalities.



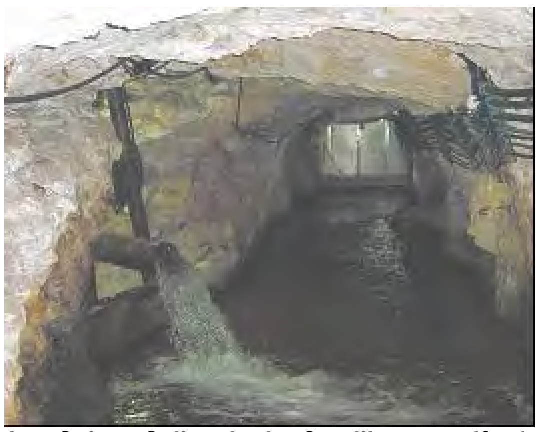


**Figure 23: Location (left) and picture (right) of the Los Suizos Gallery in the Crevillente aquifer (adapted from Andreu et al., 2002 and Bru and Andreu, 2006).**

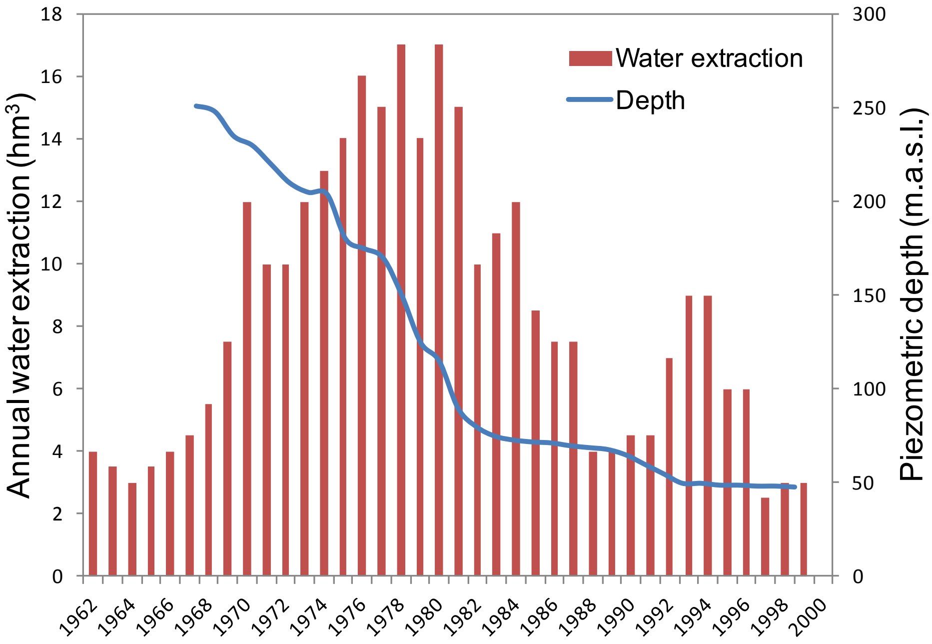



**Figure 24: Piezometric dynamics in the western area of the Crevillente aquifer (adapted from Andreu et al., 2002)**

There are many artificial channels in the area for both inter-basin transfers and water redistribution. The Tajo-Segura inter-basin transfer is of particular interest, as it is an important source of water for both irrigation and domestic supply in the area. It crosses Albatera municipality from West to East, around 2 km south of the Albatera-Crevillente range.

### 3.1.7 Main Ecosystems

***Thermo-Mediterranean shrublands***

The natural climate-driven vegetation communities in Albatera site are thermo-Mediterranean shrublands, dominated by deep-rooting tall shrub species that are particularly adapted to water scarcity and extreme summer drought conditions. In healthy shrublands, total plant cover is relatively high (> 60%), and consisted of big patches of tall shrubs within a matrix of grasses, subshrubs, chamaephytes and bare soil. The most common tall-srub species in this type of communities are: *Rhamnus lycioides*, *Quercus coccifera*, *Pistacia lentiscus, Olea europaea ssp sylvestris*, *Juniperus oxycedrus*, *Osyris quadripartita*, *Ephedra fragilis*, *Chamaerops humilis* and *Witania frutescens*. Most of these species are resprouting species that can regenerate from the root collar if burned or cut. Few patches of well-preserved tall-shrubland can be found in the area, mainly on high-altitude rocky areas, where rock outcrops and difficult access have prevented or decreased the (marginal) agricultural use of the land, and on relatively humid swales, where higher water availability has allowed a good development of this type of plant communities (Figure 25).

**Figure 25: General view of a well-preserved shrubland area in Albatera Study Site (Photo: S. Bautista).**

***Degraded and reforested/afforested ecosystems***

Intense land exploitation, which often included uprooting of resprouting species, has led to changes in vegetation towards ecosystems dominated by subshrubs and tussock grass species, with very low plant cover (around 30%) on a matrix of degraded bare soil (Figure 26). Dominant species in these degraded communities are subshrubs such as *Globularia alypum*, *Rosmarinus offcinalis*, *Cistus clussi* and *Anthyllis citisoides*; chamaephyte species such as *Thymus vulgaris*, *Fumana ericoides* and *Helianthemum apenninun*; perennial grasses such as *Stipa tenacissima*, *Lygeum spartum* and *Brachypodium retusum*. The area also includes a number of scattered Aleppo pine (*Pinus halepensis*) forest patches, which have resulted from past reforestation programs implemented in the area, mostly through terracing.

**Figure 26: General view of degraded scrublands and steppes in the Albatera Study Site (Photo: S. Bautista).**

### *General recent dynamic of vegetation health in Albatera Site*

A synoptic view about vegetation health and the associated function of ecosystems can be derived from analysis of archival and on-going sequences of NDVI. Figure 27 depicts NDVI change through time. NDVI in the study area shows a slightly decreasing trend since the 1980s as well as a reduction of the osculation width. Taking into account the relative stability of precipitation, this change could be interpreted as a sign of reduced vegetation productivity possibly due to land degradation.

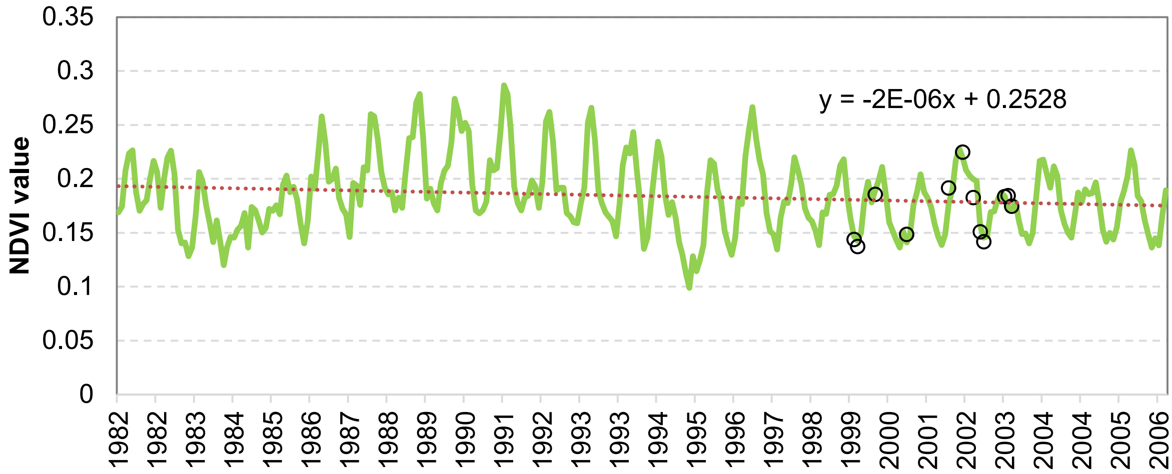



**Figure 27: Historical evolution of NDVI through time (green) corrected for bias using value from LandSat imagery (black points).**

### *Selected ecosystems for CASCADE assessment*

Four types of ecosystems or landscape units, representing different levels of degradation, have been selected for the assessment of degradation and restoration impacts on ecosystem services provision in Albatera Study Site: (a) Healthy (remnant) Mediterranean shrublands; (b) Degraded dwarf shrublands; (c) Old pine reforestation on terraces (Figure 28 and Figure 30), implemented on 1970s-80s; and (d) Restored shrublands (multispecies plantation; 2004-06).

**Figure 28: View of Albatera Study Site showing natural shrublands (background) and reforestation terraces (foreground) (Photo S. Bautista)**

### 3.1.8 Socioeconomic status

Before the 1950s, the economy of Albatera municipality was fully relying on agriculture, originally based on both irrigated farming, in the low lands of the Segura river basin, and rainfed crops, located mainly on terraces of the lowest parts of the mountain-range and on the transition areas between the range and the low lands. During this period, the mountain range area also supported some marginal activities such as alpha-grass harvesting (for fibre production) and wood gathering (for firewood). Grazing was moderately important before the 1950s. For example, in 1910, the livestock census for Albatera was around 1,000 animals (evenly distributed among sheep, goats, pigs, mules, horses and donkeys), which is considered to be the total livestock capacity for the area. At that time, Albatera had a population of 4,050 inhabitants. The trade of pigs was important in the 19th and first half of 20th century, but no other commercial or industrial activity was relevant in the municipality. In general, average family farm income was low, a fact that led to several migration pulses, mostly during 1900-1925 and in the 1950s.

During the second half of the 20th century, major socio-economic changes resulting from the widespread use of fossil-fuel derived products, industrial development and intensification of tourism, led to general rural land abandonment in Spain. In Albatera, agriculture abandonment mostly affected rainfed crops and agricultural terraces located on (or near to) the mountain range. Grazing, wood gathering, alpha-grass harvesting and other marginal activities on the mountain range also ceased. Despite this process of land abandonment, the economy of Albatera continues mainly relying on irrigation farming (mainly lemon and orange tree crops and other fruit-tree crops such as pomegranates and figs) located on the low lands and transition areas between the low lands and the mountain range. However, the fragmentation of agricultural land, the spread of second-home urbanisations, and the aging of the population of farmers (and associated increase in part-time agriculture) are processes that challenge the future of agriculture in Albatera. Textile and building-sector industries, commerce and an incipient tourism industry are recently gaining economic relevance in the municipality and have contributed to a significant population increase in recent years (from 8,811 inhabitants in 2000 to 11,936 inhabitants in 2012).

Since the late 19th century, the mountain range area has been of public domain, belonging to the municipality of Albatera but being jointly managed by the Forest Service of the Valencia Regional Government and the municipality. The Albatera Study Site is located on “forest land”, which is the main land use on the mountain range. No farming activity is currently allowed in the area. At present, the exploitation of natural resources on the mountain range is limited to small-game hunting (rabbits; partridges) and snail harvesting, although limited grazing can sporadically take place in the area.

In 2002, the association of irrigation-land owners of the area signed a concession agreement for the exploitation of Los Suizos Gallery for 99 years, which includes the right for improvement, maintenance and repairmen works on the gallery and associated distribution channels.

### 3.1.9 Timeline of events

The most important recent changes and milestones that occurred since the 1950s in the natural and social environment of Albatera site and are relevant for understanding current land condition are included in Figure 29. Prior to those events, two more periods can be considered important:

1900-1920s: several migration pulses, triggered by the low profitability of agricultural land; associated abandonment of marginal agricultural and grazing on the Albatera-Crevillente range slopes.

1920s-30s: sharp increase in irrigation land, with associated decrease in migration rate.

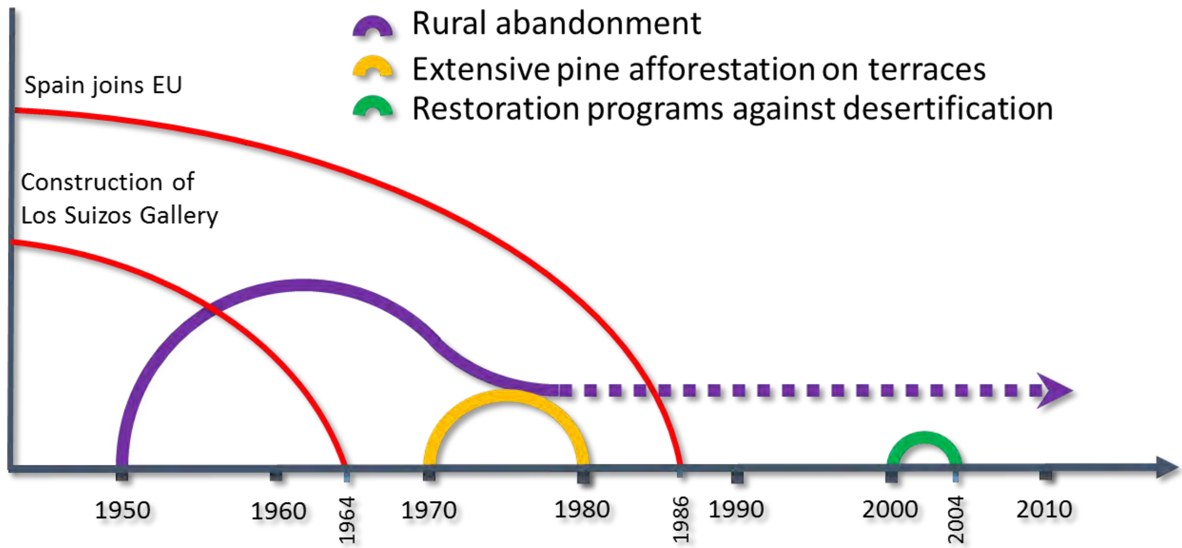



**Figure 29: Event timeline for Albatera since the 1950s.**

## 3.2 Main Causes of Land Degradation

### 3.2.1 Human induced Drivers

As in most dryland areas of the Mediterranean Basin, the long-term impact of intense land use, including burning, woodland clearing, grazing, terracing and cultivation, has resulted in strongly human-modified landscapes in the Albatera area, for which the relative role played by each of those old disturbances is difficult to unravel. In more recent times, two main periods, with contrasting socio-economic conditions, are of major relevance as drivers of the current land condition in the area:

(1) Before the 1950s, the economy of the area completely relied on agriculture. Agricultural activities were originally based on irrigated farming, mainly from the Segura river waters and rainfed crops on the lowest parts of the mountain-range. At a later stage, a switch towards fully irrigated farming took place, resulting from access to additional sources of water such as inter-basin transfers and construction of new irrigation systems. During this period, the Albatera mountain-range area was exploited through a diffuse set of marginal activities including marginal agriculture, grazing, wood gathering and alpha-grass (*Stipa tenacissima*) exploitation for fibre production. The accumulated impact of these activities heavily altered the natural shrublands in the area (though still some remnant patches can be found) and promoted land degradation. The main consequences of this degradation include: loss of ecosystem functions (water infiltration and nutrient cycling), reduced productivity; very low plant cover; and net loss of resources (water, soil) from the system. In addition, off-site damages due to flooding are important in the area. According to the Land Action Plan to Prevent Flooding in the

Valencia Region (PATRICOVA, Regional Government), the Albatera-Crevillente range is one of the hot spots of flooding risk in the province of Alicante.

(2) During the second half of the 20th century, major socio-economic changes that occurred in Spain led to a generalized trend of rural land abandonment. Most of the agricultural land in Albatera is family-owned, with an average property size of 1.8 ha and relatively low productivity value, which has fostered rural land abandonment and the development of commercial and industrial activities in the area. Nowadays, further fragmentation of agricultural land is taking place in response of demands for other land uses (e.g. second-home urbanisations and part-time agriculture). Resource exploitation in the mountain-range area has mostly ceased, with the exception of some terraced crops enclaves in the lowest parts of the range and the water-mining system of Los Suizos gallery. Grazing is almost absent in the area.

Several afforestation/reforestation programmes have taken place in this period. These actions, mainly aimed at controlling erosion and floods, have yielded poor results. Unsuccessful reforestation through terracing (Figure 30) and maintenance works on the pipe system for water distribution from the Los Suizos gallery have further altered and degraded the landscape. In recent years, a new set of restoration actions have been implemented in the site by the Valencia Region Forest Service and the Spanish Ministry of Environment. These actions mainly consisted of multi-species and spatially heterogeneous plantations designed to combat the multifaceted land degradation of the area. The selection of plant species was focused to match the diversity of habitats, landscape functional units, and natural patterns in the target area.

**Figure 30: Degraded reforestation terraces in Albatera Study Site (Photo: S. Bautista).**

### 3.2.2 Natural Drivers

Long-period drought assessment represented by 48-month SPI (Standardized Precipitation Index) provided an overview of prolonged drought occurrence during the period 1963-2011 (Figure 31). Both prolonged droughts and wet periods are common in the area, reflecting the well-known inter-annual heterogeneity in precipitation of arid and semiarid lands. However, dry periods were more frequent than wet periods. Severe long droughts took place during 1963-65, 1983-85, and 1994-96 (Figure 31). Mild drought conditions were also observed during the period 2000-02. It should not go unnoticed that the severe droughts of 1983-85 and 1994-96 coincide well with two instances of extreme NDVI decline with respect to neighbouring values (Figure 27). Given the low resolution of the NDVI analysis at this point, the spatial extent and gravity of the effect of those droughts appears substantial.

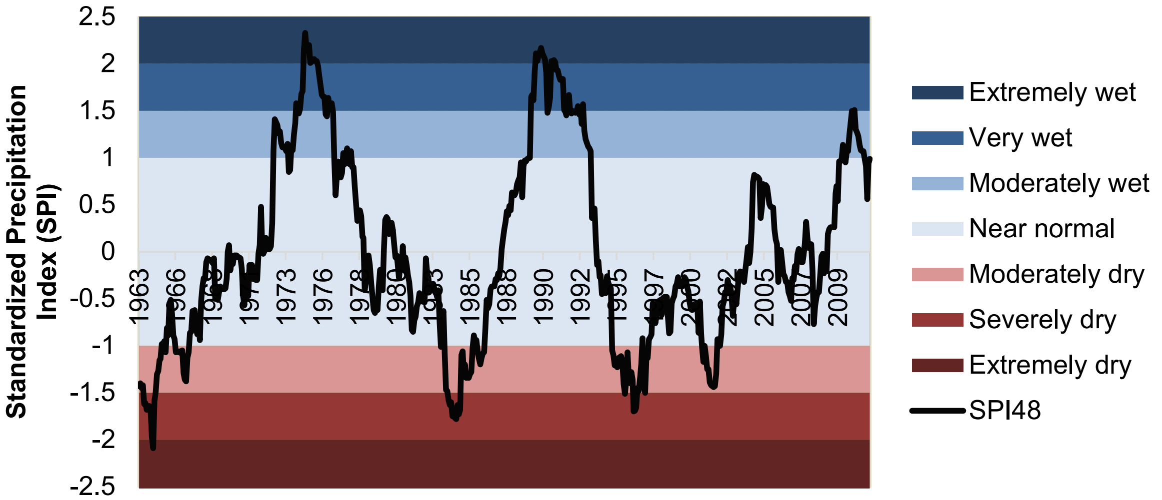



**Figure 31: SPI 48 estimated for the period 1963-2011 for the area of Albatera.**

Regarding the aridity index, the area displays stability within the arid bracket with few years that crossed over to a semi-arid character, and two years (1962 and 1995) that approached hyper-arid conditions (Figure 32). Although less evident, 1983-85 and 1994-96 also appear as important milestones for the fate of the local climate and ecosystem.

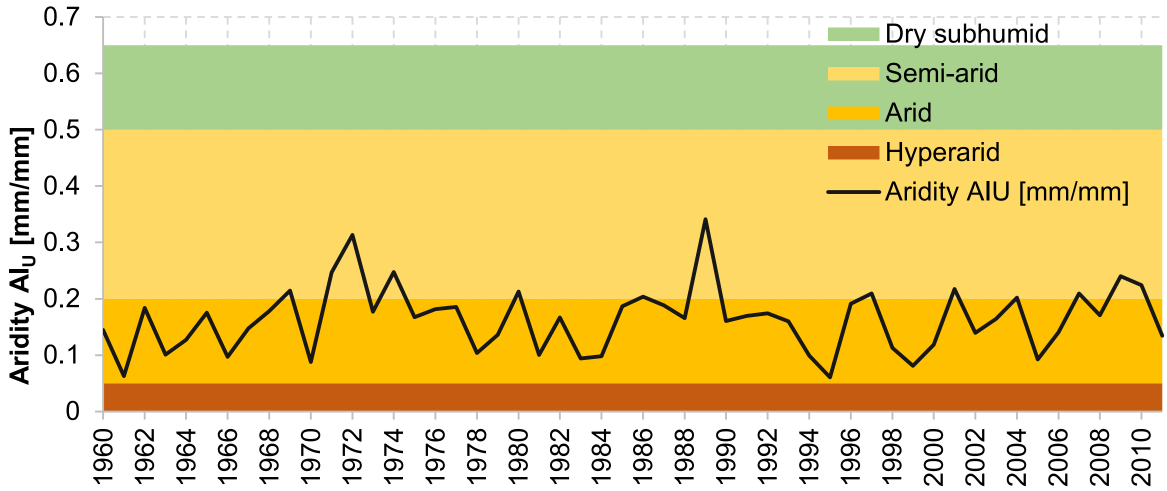



**Figure 32: Aridity estimated for the Albatera Area.**

# 4 Ayora Study Site (ES)

Responsible partner: CEAM (14)

## 4.1 Definition of the Ayora Study Site

### 4.1.1 General information

The study area is located in the interior of Valencia, eastern Iberian Peninsula (39º05 '-40º5' N, 0º51' - 1º59' W) as shown in Figure 33 is located in Eastern Spain within the Autonomous Community of Valencia. The Ayora Valley is located on the border of the provinces of Albacete and Alicante, running between the mountain ranges of Sierra Palomera and Mugrón to the west, and Cortes de Pallás and the Caroig Peak. A multitude of forest tracks crossing the valleys and bordering the mountains shape the landscape of Ayora. The region resembles a typical landscape of inland Mediterranean zones and contains a rich variety of fauna and flora.

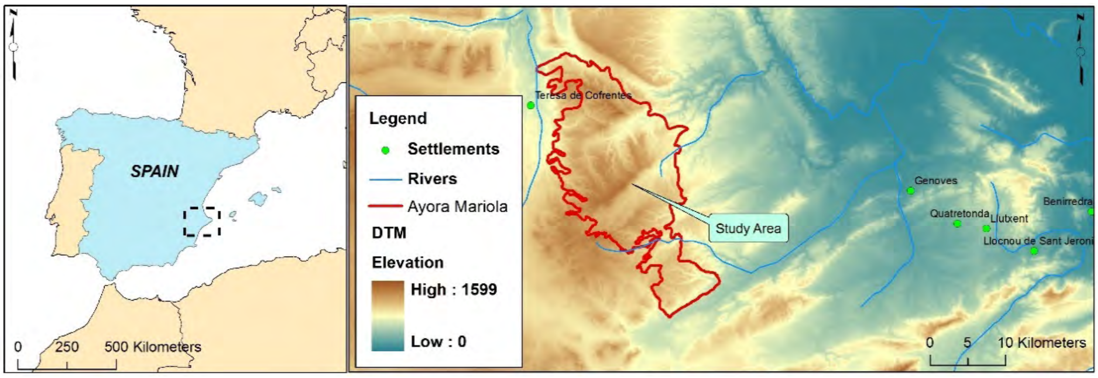



**Figure 33: Study area – Ayora.**

### 4.1.2 Topography

The Ayora Region covers an area of approximately 3,300 km$^2$. In general terms, the region is characterized by a diversified and rugged topography. The topography is characterized by moderate to steep slopes, partially covered with agricultural terraces that are currently abandoned and degraded. Altitude ranges from 20 m to nearly 1,200 m. The central part consists of an undulated area with an average elevation of about 600-700 m, which is interrupted by steep slopes and the valleys of the rivers Rio Grande and Escalona draining the region in easterly direction into the Jucar river and to the coastal plains. West of this central area, running straight from south to north, lies the Ayora-Cofrentes valley (Rodriguez Gonzalez et al., 2008).

### 4.1.3 Geology and Soils

The dominant soils in the area are Regosols developed over marls and limestone colluviums. As secondary formations, shallow Leptosols and Luvisols developed over limestones can also be found. According to the JRC WRB Soil Geographical Database (excerpt shown in Figure 34), dominant soils in the basin are Leptosols, with the exception of the north-west part where they give their place to Cambisols. According to the same source, calcaric soils are dominant across the area (Figure 35).

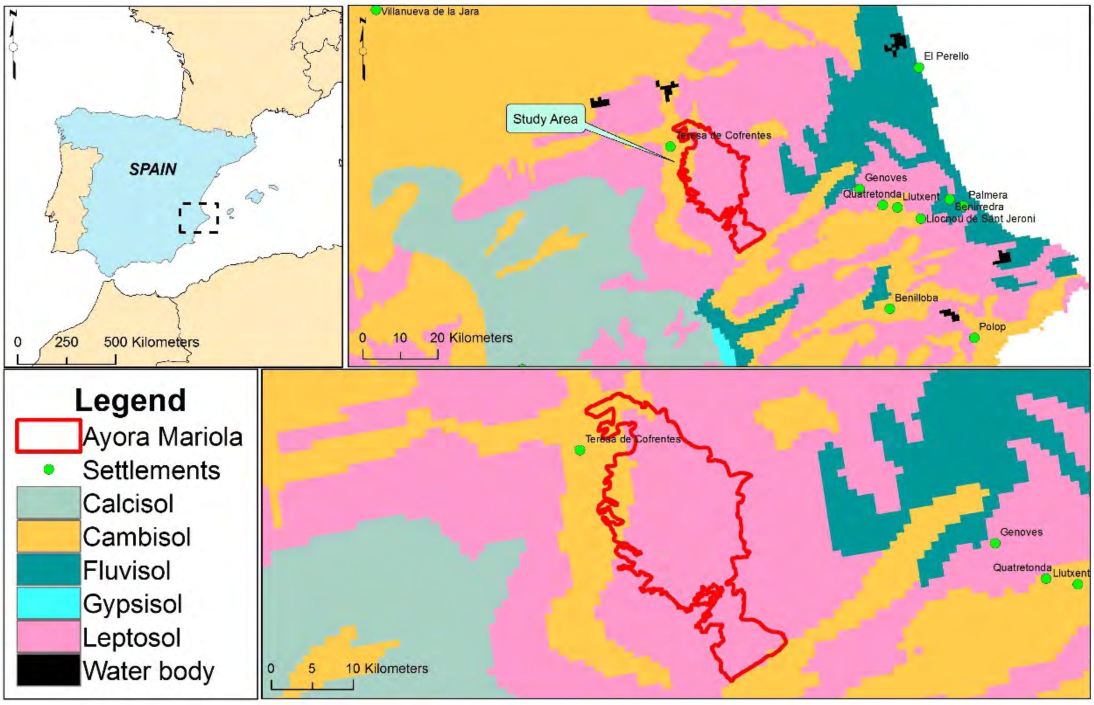



Figure 34: Soil groups according to the FAO classification in the Study Site (Source: JRC).

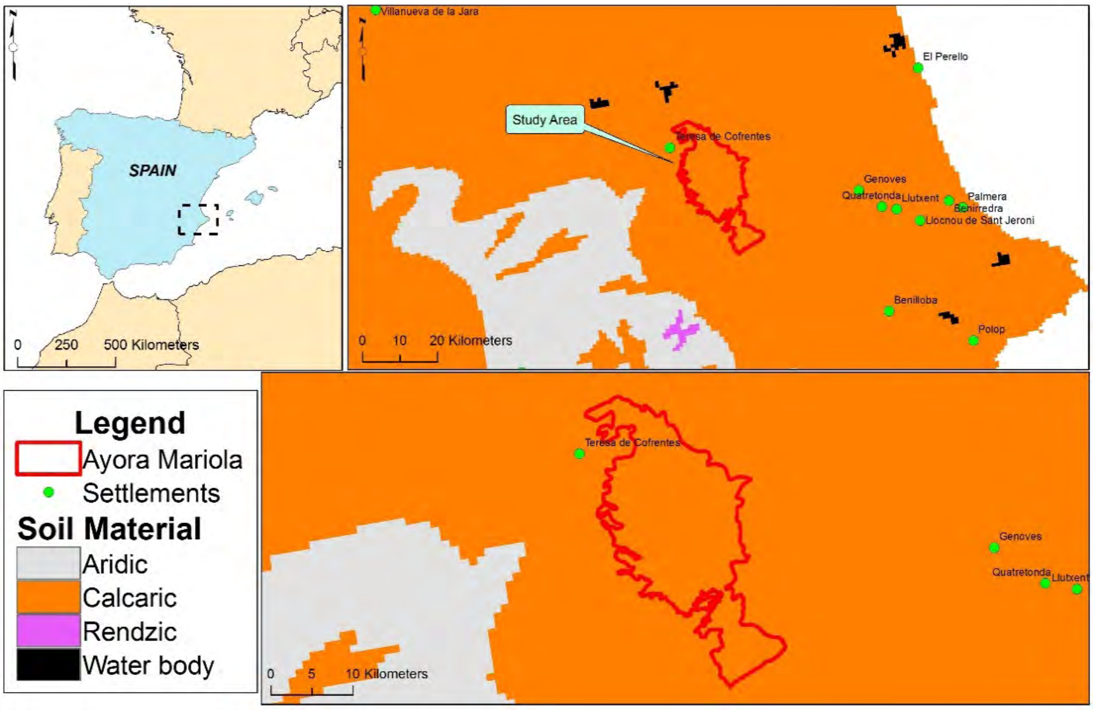



Figure 35: Categories of Soil Materials (WRB) in the Study Site (Source: JRC).

### 4.1.4 Land Use

Over the last 30 years there have been significant changes in land use distribution in Ayora. In the past decades, the region has been subject to widespread land abandonment and significant changes in land utilization schemes. This has led to the encroachment of shrubs and accumulation of flammable biomass which has often served as fuel for wildfires. As such, land use change due to abandonment may therefore be the responsible factor for changes in the fire regime. Rangeland is the major land cover in the area, as it accounts for 67% of the Study Site. Within this cover, shrublands are dominant (Figure 36). This can be attributed to the previously abandoned that has become recolonized and eventually encroached. Besides these changes, documentation of land use in CORINE datasets appears relatively stable since the 90s.

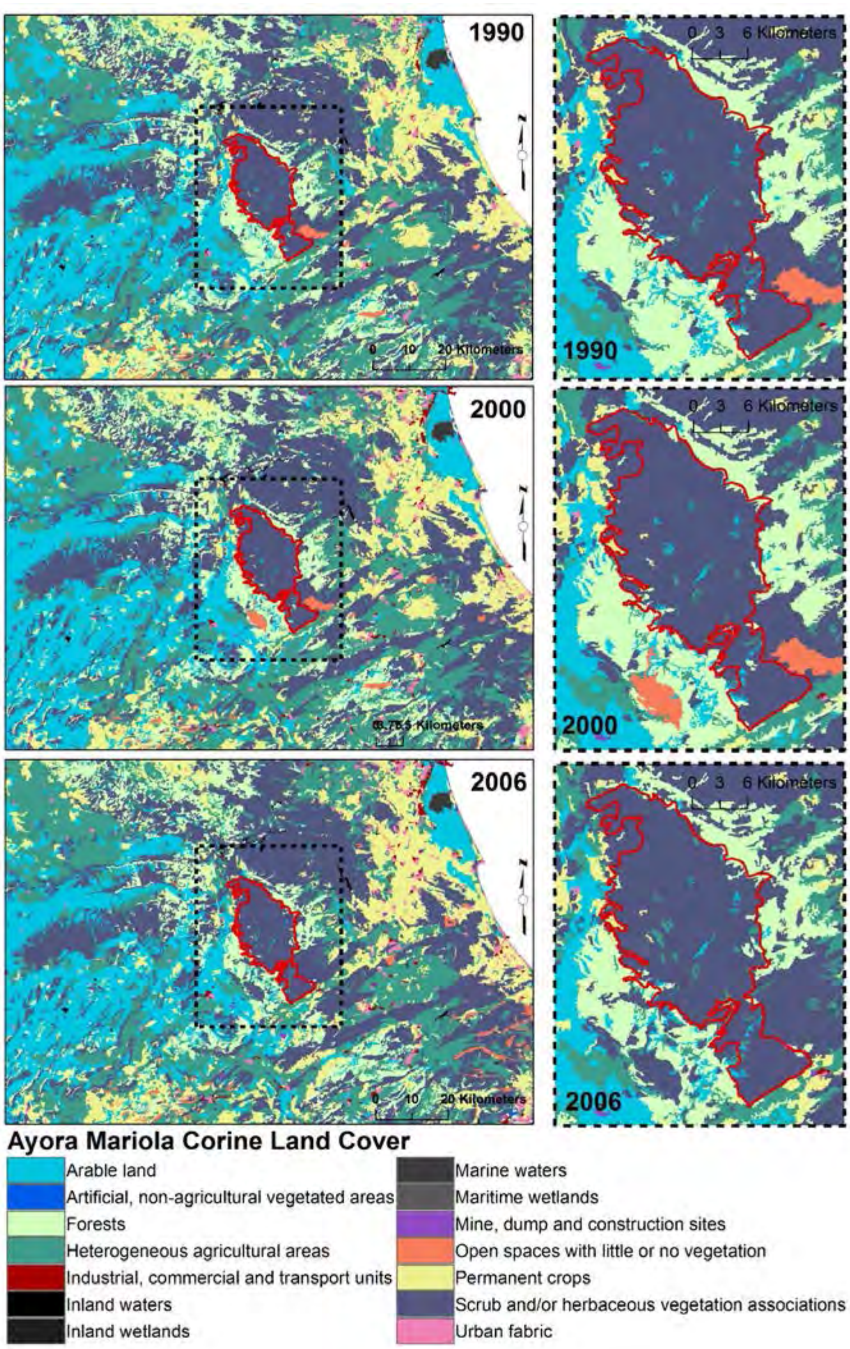



**Figure 36: Land use in the Study Site (Source: CORINE, JRC).**

Following a large fire event in 1979, a number of management interventions and mitigation schemes were introduced, such as afforestation efforts (*P. halepensis*, less frequently *P. pinaster* and *Q. ilex*), mechanical fuel load reduction and reduction of competition among plants, the creation of fire breaks and the installation of water tanks. As a result of both the remote sensing based analysis and field inspections these actions were mostly rated as not successful, as wide areas were burned at least one more time after the 1979 fire event.

### 4.1.5 Climate

The climate in Ayora is typically Mediterranean, with hot and dry summer months and a mild winter. The dominant climate is dry Mesomediterranean (Rivas Martínez, 1987) with mean temperatures from 13 to 17 °C and an annual mean rainfall between 350 and 700 mm, showing a bimodal distribution with main maximum rainfalls in late autumn and early winter months, and a secondary maximum in April or May (Rodriguez Gonzalez et al., 2008). The distribution of precipitation differentiates two zones: a colder and drier northern zone with 380-500 mm precipitation and a southern zone with a greater marine influence reflected in milder temperatures and higher precipitation (500 -700 mm) (Baeza et al., 2007). Though all months receive rainfalls, the dry season between July and August–September limits the vegetative period to 8–11 months. Potential evapotranspiration reaches its yearly maximum during summer, causing a negative regional water balance and extremely low moisture content of the vegetation cover, and a very high fire-proneness in the region. Figure 37 shows the mean monthly precipitation measured at the station of Ayora (Ayora CHJ, UTMX 668702, UTMY 4326428, 641 m asl) which has a relatively stable long term average with mean annual precipitation of about 500 mm (or about 42 mm/month).

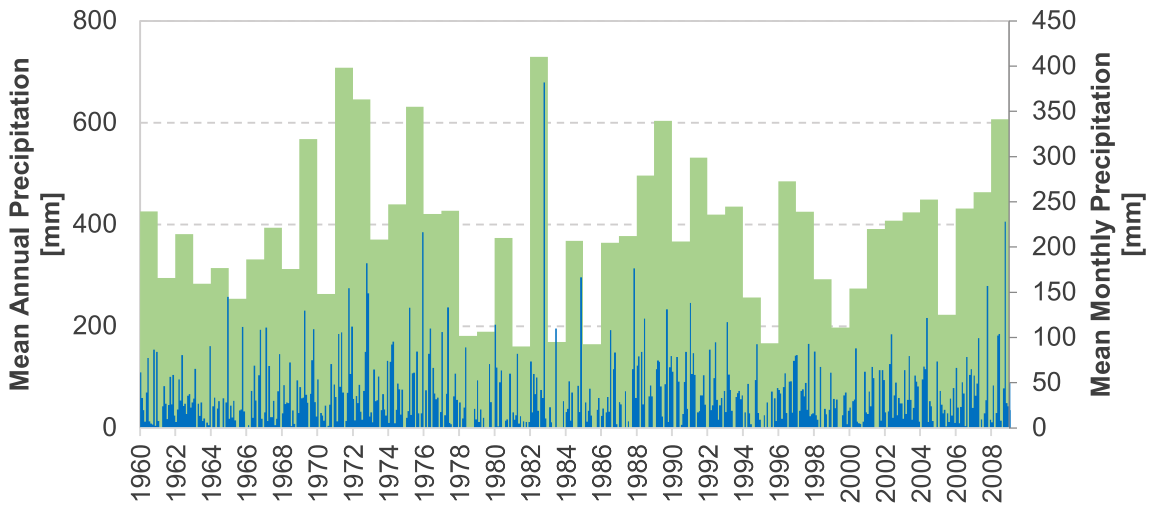



**Figure 37: Mean monthly precipitation measured at Ayora, CHJ.**

Figure 38 shows the mean monthly temperature at the Study Site as it was estimated from the E-OBS dataset (Haylock et al., 2008). For the available record, temperature shows only a slight upward trend and remains stable at an annual mean of 16.6 $^{o}$C. The potential evaporation for the Study Site was estimated at 1,325 mm using the E-OBS dataset and the Blaney-Criddle equation (Blaney and Criddle, 1962).

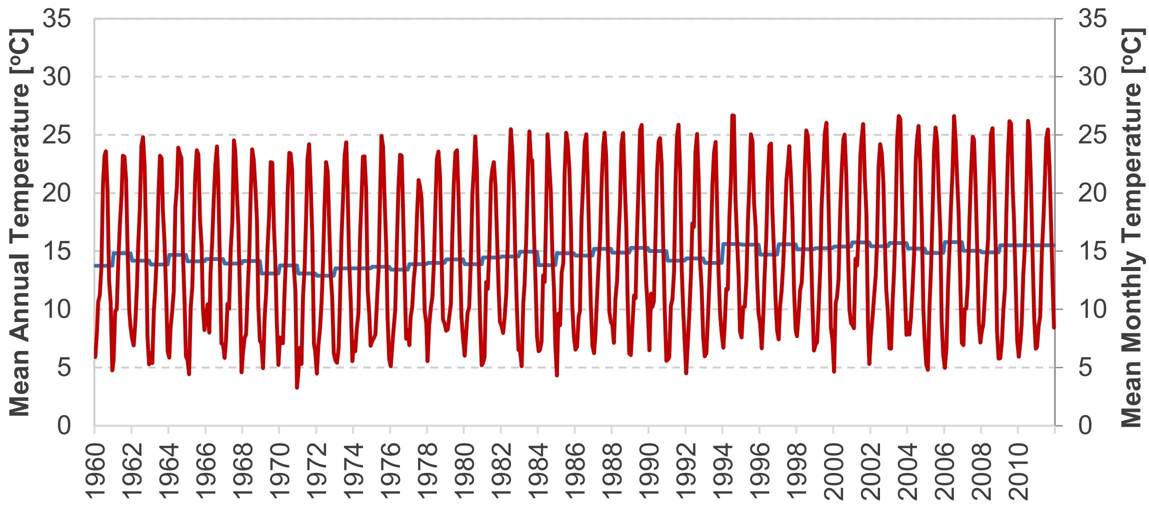



**Figure 38: Mean monthly temperature at Ayora derived from the E-OBS dataset and corrected for bias.**

### 4.1.6 Main Ecosystems

***Flora***

Rangelands, accounting for 67% of the total land use, are largely dominated by dense shrublands and, to a lesser degree, by pine forests. These shrublands consist mainly of Quercus coccifera oaks with Ulex parviflorus and/or Rosmarinus officinalis. The pine forests are dominated by Pinus halepenensis and more rarely Pinus pinaster. Today, the typical Mediterranean woodland formations of Quercus ilex, P. pinaster and Pinus halepensis are only found on small remote and isolated areas. Agriculture is concentrated on the more suitable areas of the eastern plains and along the Ayora-Cofrentes valley. The mountainous areas, which were once under traditional, labour intensive cultivation, are now abandoned. This has led, in particular at the end of the 1960s and the beginning of the 1970s, to high fuel concentrations on once cultivated areas enhancing the natural fire-prone environmental conditions of the region.

1.- Trees

1.a Unburned pine forests. These areas present a continuous litter layer covering the whole soil surface, mainly composed by pine needles from groups of mature *P. pinaster* individuals. The understorey (0.5 – 1.5 m height) consists of resprouter shrub species such as *Juniperus oxycedrus*, *Quercus coccifera*, and *Rhamnus alaternus*, and a heavy grass layer (*Brachypodium retusum*). Noteworthy is the presence of other tree species, like *Juniperus phoenicea* and *Quercus ilex*, germinated probably thanks to jays that would profit the presence of mature individuals scattered in cropland areas.

1.b Regenerated pine forests. This vegetation type can be found in areas where only one fire event has occurred. The regeneration of *Pinus pinaster* is, in general, low and located in north facing and less exposed slopes where the environmental conditions are more suitable for the establishment of this species. *Pinus halepensis* shows higher regeneration than the above mentioned *Pinus* species, and therefore this will likely be the dominant tree vegetation in the area in the near future, if no further disturbances occur. The density of the regeneration will mostly depend on slope exposures, certain soil properties and to the marine influence (higher rainfall records in the SE part of the burned area than in the central and NW ones).

1.c Unburned holm oak forests. There is a *Quercus ilex* stand in the eastern part of the Study Site, and probably its core has not been affected by the 1979 fire. This patch is settled in the lowest part of the area (700 m) on decarbonated and deep soils developed over limestones and surrounded by old crop fields.

2.- Shrublands

Shrublands can be classified attending to the presence and dominance amongst the plant species, resulting in both mixed and pure shrublands. This probably reflects land uses, soil properties and disturbance regimes (mainly fires).

2.a Kermes oak shrublands (*Quercus coccifera*). This community usually occurs on red and brown fersiallitic soils developed from limestones and dolomites, probably because these soils were never cultivated. This vegetation forms continuous and dense shrublands dominated by resprouter species, especially *Quercus coccifera* and isolated individuals of tree species (*Quercus ilex* and *Q. faginea*). The development stage of this community in the study area depends on the fire frequency.

2.b Gorse shrublands (*Ulex parviflorus*). High presence in set-aside agricultural lands on soft substrates (marls). Obligate seeders are the dominant species, with low presence of resprouter shrubs. Mediterranean shrublands accumulate significant amounts of dead standing biomass (necromass) over time, thus increasing wildfire risk. Some plots within the study area show such heavy fuel accumulation due to the stand age (24 years) that has reached the senescence stage.

2.c Mixed shrublands. In areas burned twice (i.e. 1979 and 1991, for a total surface of ca. 4,800 ha) we find communities without a clear dominating species. The vegetation is composed both by resprouter (*Q. coccifera*, *Juniperus oxycedrus*, *Rhamnus alaternus*, *Erica multiflora*) and obligate seeder (U. *parviflorus*, *Cistus* spp, *Rosmarinus officinalis*) species, varying in its relative weight. The resprouter shrubs are distributed in small patches leaving open spaces between them that are occupied by seeder shrubs. The area is characterized by a continuous alternancy of limestones, dolomitic and marly soils. One of the most abundant plant species is kermes oak (*Quercus coccifera*) but it is substituted by heath (*Erica multiflora*) on marly soils.

2.d *Cistus* spp. shrublands. The areas dominated by Mediterranean gorse, when burned again (in 1991 or 1996) usually generate shrublands dominated by *Cistus* spp. (especially *C. albidus*). This community is sparser than the previous mentioned and the presence of resprouter shrub species is almost non-existent, although the vegetal cover due to resprouter grasses (mainly *Brachypodium retusum*) is high.

A synoptic view about vegetation health and the associated function of ecosystems can be derived from analysis of archival and on-going sequences of NDVI. Figure 11 depicts NDVI change through time (green line using datasets from (Pinzon et al., 2005; Tucker et al., 2005) using LandSat 7 satellite imagery. NDVI in the study area shows a slight upward trend since the 1980s.

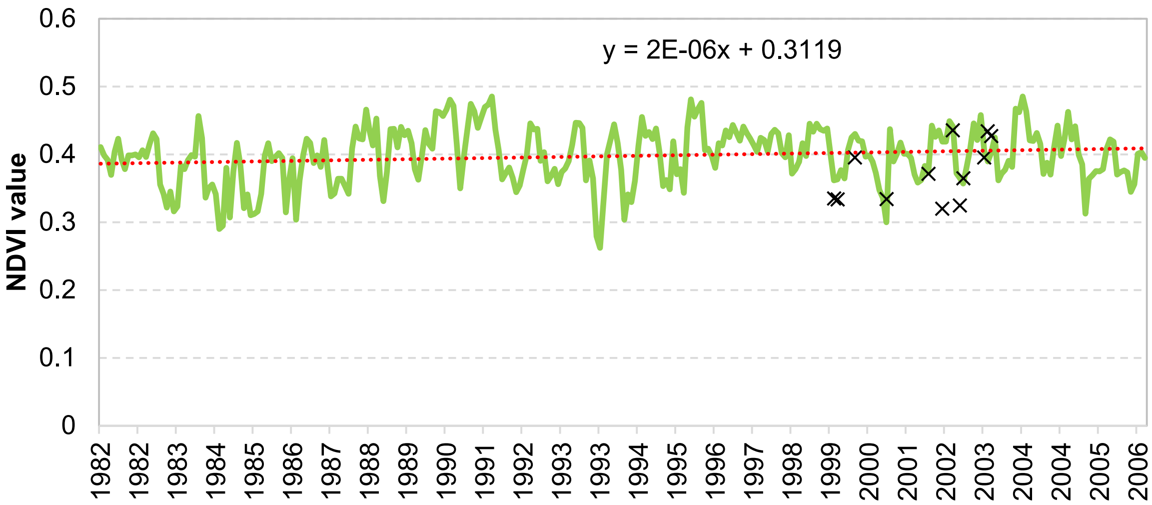



**Figure 39: Historical evolution of NDVI through time (green) corrected for bias using value from LandSat 7 imagery (black crosses).**

***Selected Vegetation – soil system***

Forest and agriculture represent the main land uses in the Valencia field sites. During the 20th century many cultivated areas were abandoned and recolonized by early secondary successional species or, frequently, planted with pines. Colonization by later successional species (e.g. *Quercus* spp) used to be rather slow and always dependent on the presence of nearby preserved natural ecosystems and animals that disperse the seeds. As a consequence, a common landscape at the mid- and long- term in these former agricultural lands is a pine forest with a well-developed understory where seeder species are dominant (Figure 40). These communities are characterized by a large accumulation and packaging of standing biomass conferring a very high fire hazard to the system.

**Figure 40: Pine forest of Aleppo pine (in the background) and shrubland dominated by gorse and rosemary (in the front). They correspond to areas burned once and twice, respectively.**

Wildfires represent the degradation driver in the Valencia field sites. They showed an exponential increase from the 60s to the 80s of the 20th century both in the number of fires and the burned surface (Pausas et al., 2009). Therefore, the landscape is a mosaic of pine forests and shrublands that differ in their composition and structure. The tree layer, when present, consists in *Pinus halepensis* (Aleppo pine) and *P. pinaster* (maritime pine) individuals either in pure or mixed stands. Seeder species dominate the shrub layer, being the main species *Rosmarinus officinalis* (rosemary), *Ulex parviflorus* (gorse) and *Cistus albidus* (rockrose) (Figure 40 and Figure 41). Resprouters like *Quercus coccifera* (kermes oak) are also present within the shrubland but in lower proportion than seeders.

**Figure 41: Low and sparse shrubland dominated by rockrose. The picture corresponds to an area burned three times.**

Leptosols, stony and shallow soils formed on limestone and dolomite (hereafter limestones), dominate in the uplands of the study area while Regosols, less stony and deeper soils formed on marl (hereafter marls), dominate in the lower colluvial areas (Baeza et al., 2007).

### 4.1.7 Socioeconomic status

The little economic activity taking place in the area is mostly associated with livestock. Before the 1979 wildfire, animals grazed the rangeland. As forest gave its place to dense shrublands after the fire, sheep were mostly confined to croplands that were easier to navigate. In limited cases, administrative subsidies allowed grazing in firebreaks in order to assist in their maintenance. On the other hand, goats are able to feed in shrublands but the number of animals is much lower than that of sheep (ca 3,000 vs 12,000). Furthermore, beekeeping is an important economic activity in the region. The big 1979 wildfire also resulted in a reduction of the logging exploitation of the forest from 24,000 to

2,000 m[3] of wood per year. At present, more than 19,000 ha are cultivated in the Ayora valley, mainly cereals and olive, fruit and almond groves. This represents 17% of the total surface area of the region. The population employed in agriculture passed from 20 to 5.6% in 15 years.

### 4.1.8 Timeline of events

The most important relevant events in Ayora are two fire incidents in 1979 and 1991 which incinerated approximately 30,000 and 50,000 ha respectively. The land tenure status has changed significantly, especially after the 1979 fire (Figure 42). Of lesser importance is the introduction of the Common Agricultural Policy (CAP) in Spain with its entrance in the EU in 1986.

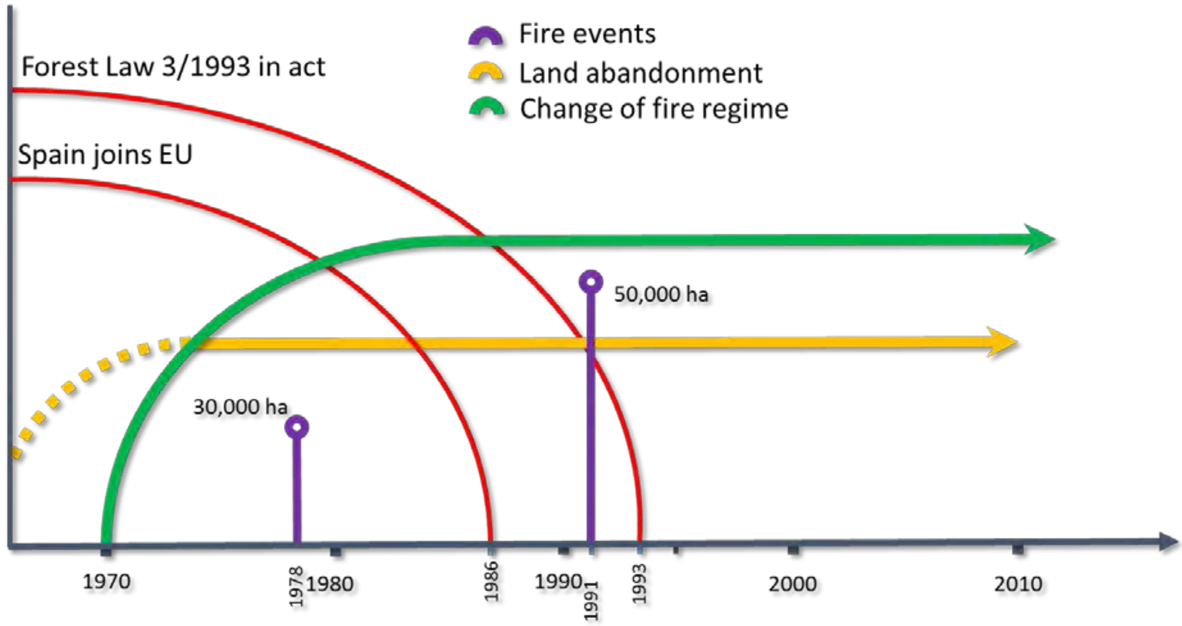



**Figure 42: Event timeline for Ayora since the 1970s.**

## 4.2 Main Causes of Land Degradation

### 4.2.1 Human induced Drivers

Forest fires constitute the main disturbance regime in the Ayora region with strong effects in the landscape configuration. In the period 1975-2000 several wildfires took place in the area. Of these, the 1979 wildfire was the biggest and most devastating one. As a consequence, within the Study Site we may find different fire recurrences in such a small period of time. These forest fires have altered the composition of the forest surface, which previous to 1979 was dominated by *Pinus halepensis, Pinus pinaster* and, to a minor extent, *Quercus ilex.* At present, shrubland and pine in regeneration (represented mainly by *Pinus halepensis*) occupy most of the surface (Figure 43); there are only small and isolated surfaces with the characteristic wooded vegetation of the zone (*Quercus ilex, Pinus pinaster* and *Pinus halepensis*).

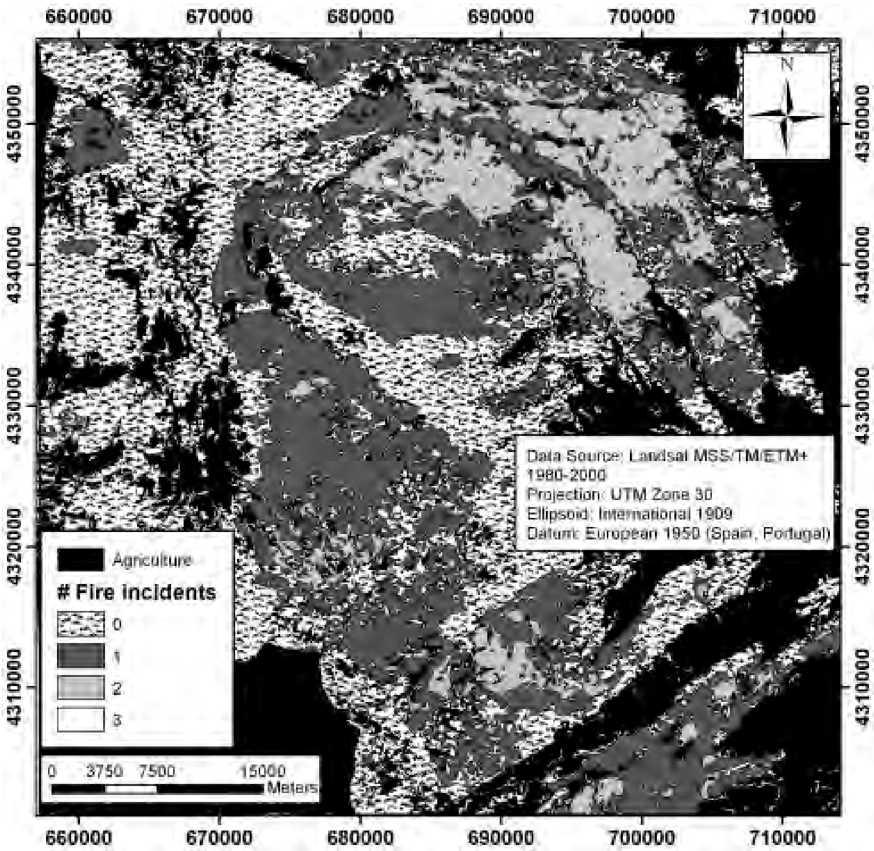
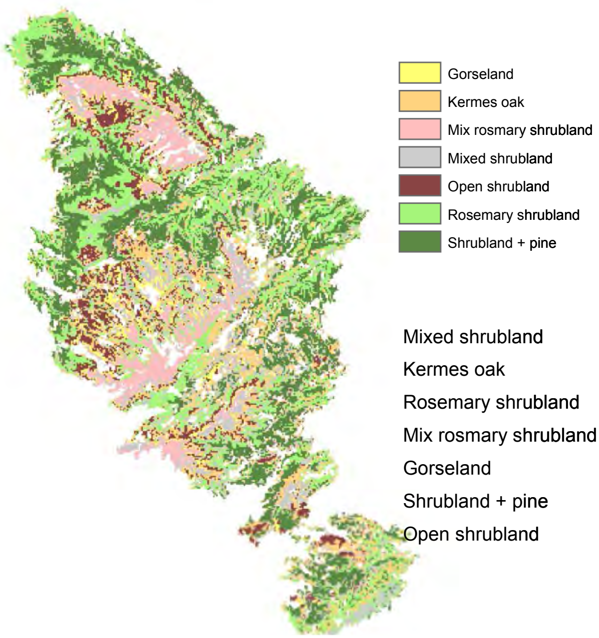



**Figure 43: Map of fire recurrences in the period 1975-2000 in the Ayora site (Röder et al., 2008)**




| | |
|---|---|
| Mixed shrubland | 15,2 |
| Kermes oak | 15,6 |
| Rosemary shrubland | 24,5 |
| Mix rosmary shrubland | 9,1 |
| Gorseland | 3,1 |
| Shrubland + pine | 23,9 |
| Open shrubland | 8,7 |

**Figure 44: Main community types in 2002 in the Ayora region burned in 1979. Their relative abundance are represented in the lower part at the right.**

The recent increase in fire incidences in the area, combined with the loss of ecosystem resilience due to past agricultural use and grazing, has driven a shift in the composition of vegetation communities, from woodlands and shrublands dominated by resprouting species to shrublands dominated by seeding species. When these shrublands are burned, further changes in plant species composition may occur, with this transition process influenced by fire recurrence. Thus, in the study area, fire recurrence is considered to drive important shifts in plant communities (from woodland to shrublands, from shrublands to open herb-sedgeland), and associated ecosystem functioning such as reduced post-fire regeneration rates leading to higher soil erosion risk. Therefore, short-interval fire cycles drive positive feedbacks that result in ecosystem degradation. Under these circumstances, the disappearance of keystone species, such as pines (due to repeated fires before producing viable seeds) and oaks (charcoaling and change of land use for cropping), represents a change in the ecosystem that needs external inputs through restoration to be reversed.

### 4.2.2 Natural Drivers

Climatic data show a general trend towards decreasing precipitation and increasing aridity in inland areas of the region of Valencia (Millán et al., 2005). In addition it has been suggested that there is a significant increase in the seasonal concentration of rainfall (De Luís et al., 2001). These trends have had consequences on the fire regime that constitutes the main degradation driver of the region. A shift in the fire regime of the region around the early 1970s has been reported, and researchers have suggested that while fire was not related to climatic conditions before 1970, since then it has been strongly driven by droughts (Pausas and Fernández-Muñoz, 2012).

Temporal analysis of drought periods carried out in different weather stations in the area does not show clear conclusions. The Standardized Precipitation Index for the period 1950-2000 shows either negative (drought increases over time), positive (drought decreases) and neutral trends (Vicente Serrano et al., 2004). The long-period drought assessment that was carried out for the study area for the period 1960-2007 (Figure 45) shows one period of extreme drought (around 1980 and two moderate to severe periods around 1986 and 2001). Prolonged drought periods are indeed not present in recent years and the SPI moves mostly in the area of normal climate. Regarding the Aridity Index, the area displayed a semi-arid character over the period 1960-2008, although values of the Aridity Index are varying substantially between years (Figure 46).

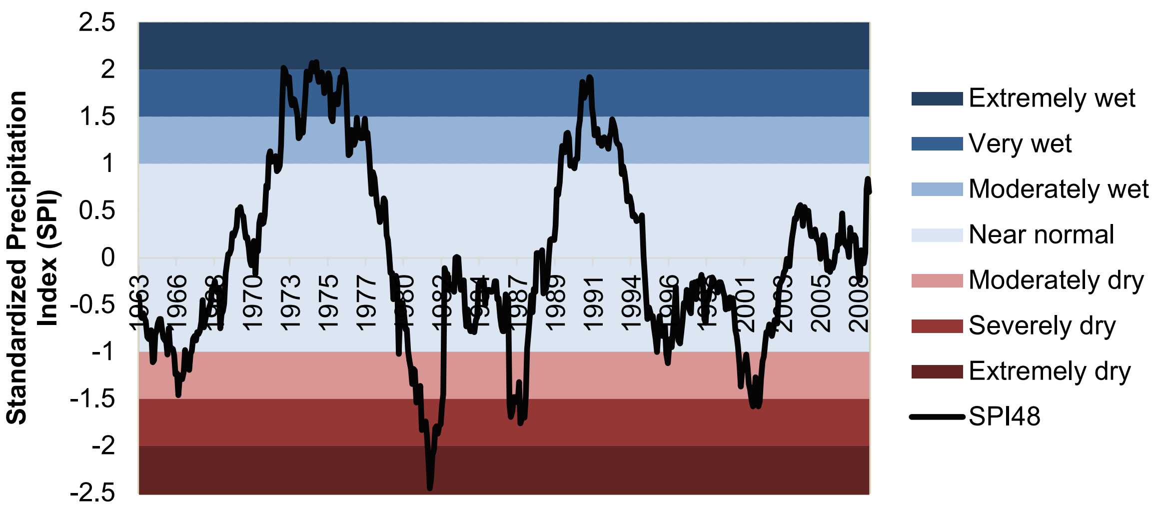



**Figure 45: SPI 48 estimated for the period 1963-2002 for the area of Ayora.**

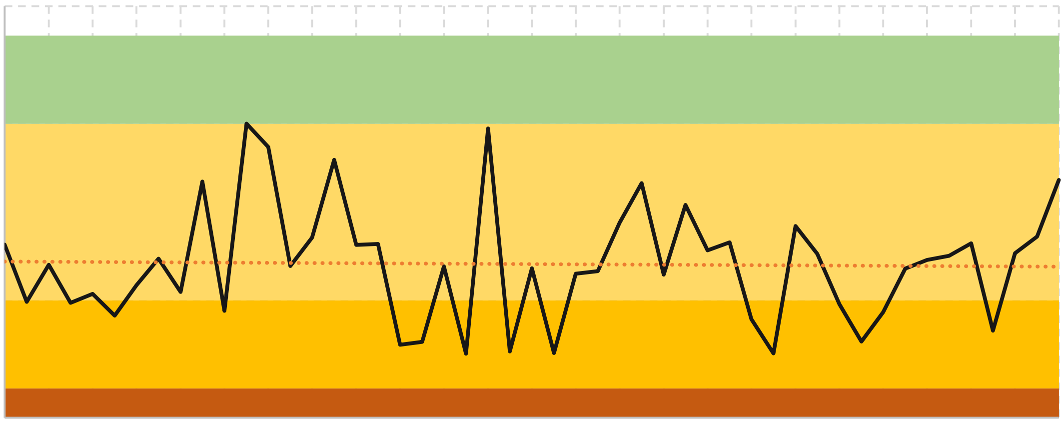


**Figure 46: Aridity estimated for the Ayora Area.**

### 4.2.3 Indirect causes

***Urbanization and infrastructure development***

Growth of cities (offsite urbanization) has resulted in the abandonment of fields and therefore to an uncontrolled growth of forests and shrublands. As a consequence, fuel accumulated and increased its continuity and, hence, the risk of fire occurrence, intensity and extension. Figure 47 depicts this extreme trend, starting from a high agricultural population density that led to over-exploitation and land-use transitions before the 50s until the rural depopulation of the 80s. The present low population density has lead to a lack of sufficient management and this in turn leads to a higher fire risk due to uncontrolled growth of forests and shrublands.

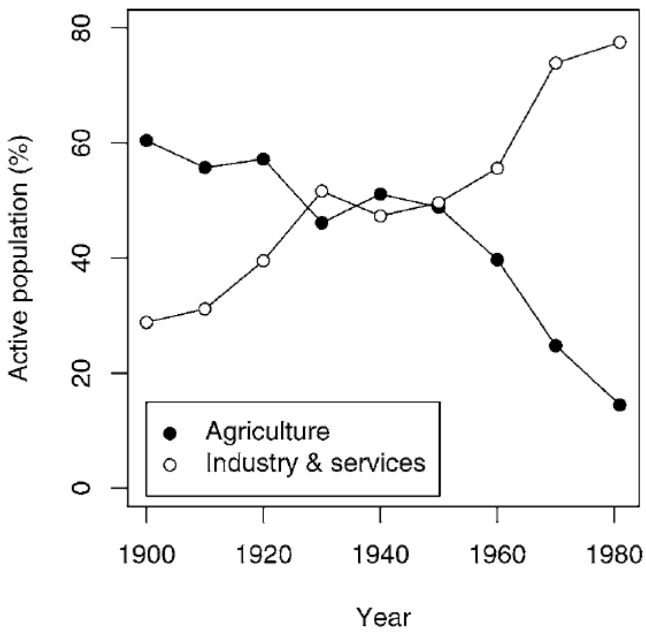



**Figure 47: Change in active population and activity sector during the 20th century.**

Today labor is again available in the area but people (especially from the cities) are less aware of the risk of fire as their livelihood depends less on forest products and health. On the contrary, the urban population tends to visit villages and their surrounding natural areas mostly for recreation. This may be particularly dangerous at summertime when rural areas increase significantly their population, vegetation is very dry and any negligence or malpractice can cause a terrible fire. Since consumption patterns and individual demand have nowadays shifted, the high demand for regional agricultural and forest products has now been abandoned. Today the area is undergrazed; grazing is not profitable anymore. Both aspects resulted in changes of vegetation composition.

Today land is both public and private in the region. The government (local or regional administrations) is only in charge of managing public land and this is only possible when there is available budget. Luck of resources can also lead to lack of good management thus increasing the fire risk. Before the great wildfire of 1979, good infrastructures to fight against the fire were lacking. After that event, new plans for fire prevention and fighting were designed and implemented to some extent. Additionally, Forest Law 3/1993 induced the implementation of conservation interventions leading to more and better managed conservation practices such as afforestation effors, and therefore a lower fire risk. Unfortunately, the current economic crisis in Spain leads to a lack of investment in forest management thus exposing Ayora to wildfires once again.

# 5 Castelsaraceno Site (IT)

Responsible partner: UNIBAS (3)

## 5.1 Definition of the Castelsaraceno Study Site

### 5.1.1 General information

The Study Site of Castelsaraceno is situated in the south-west of the Basilicata region of Southern Italy (Figure 48). Castelsaraceno has a surface area of 74.3 km$^2$ and a population of 1,507 (ISTAT, 2010) with a population density of 20.28 inhabitants per km$^2$, which is less than 1/3 that of the Basilicata Region. The Study Site straddles two national parks (Figure 49): the National Park of Pollino and the Lucano Apennine Val d'Agri Lagonegrese National Park, which constitutes a vast protected area in the Basilicata region and includes the Agri River and some of the highest peaks of the Lucano Apennines.

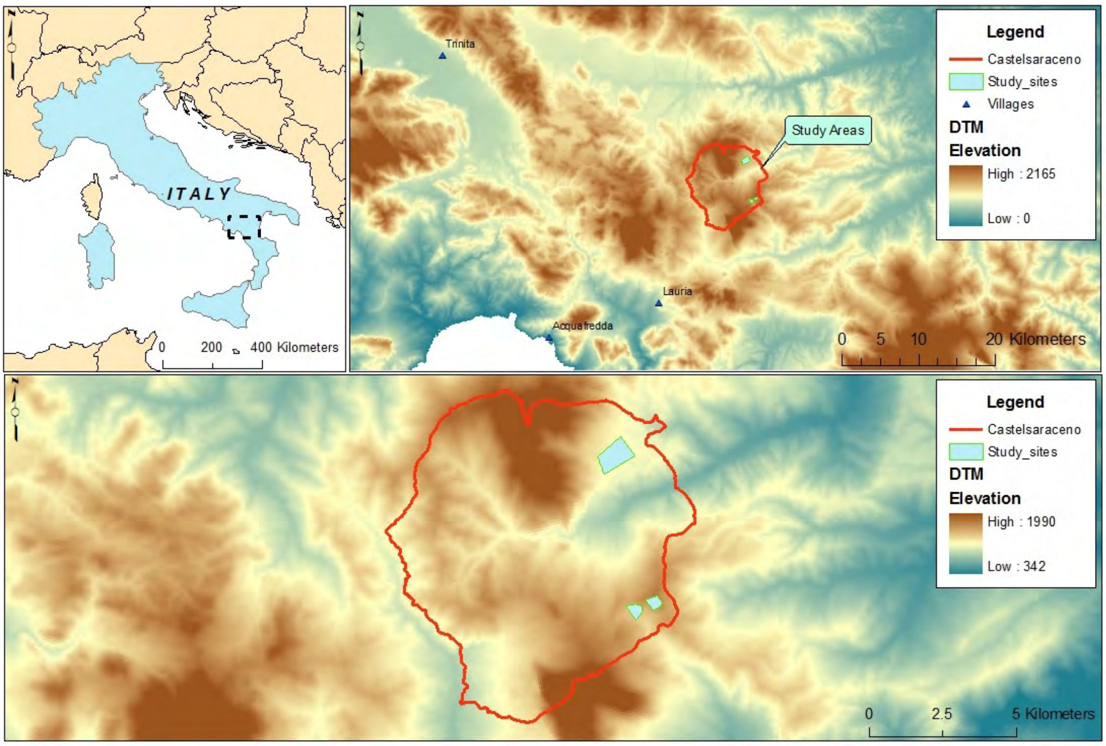



**Figure 48: Study area – Castelsaraceno.**

Castelsaraceno is a good representative of the most important environmental and socio-economic features of the Basilicata region, which has particular climatic conditions that are influenced by its orographic nature and by its proximity to two seas: Tyrrhenian and Ionian. There is a typical Mediterranean climate along the Ionian coast up to 500 – 600 m, characterised by scarce rainfall concentrated during the autumn-winter period and by heavy summer drought. Above these altitudes and up to 2000 m there is a temperate-cold climate, with mild dry summers, while a cold and rainy climate is found at the higher zones and towards the Tyrrhenian Sea. The geomorphologic aspect of the region reflects its geologic and lithological nature with both volcanic and calcareous mountains and plains made up of gravel, sand, clay and flysch, alluvial plains, fluvial terraces and alluvial cones with abundant gravel and clay-silt deposits, undergoing *Calanchive* [1] erosion. The complex alternating situations and economic and environmental importance of this region make it an ideal representative area for an analysis of the components affecting the different stages of Environmental Sensibility.

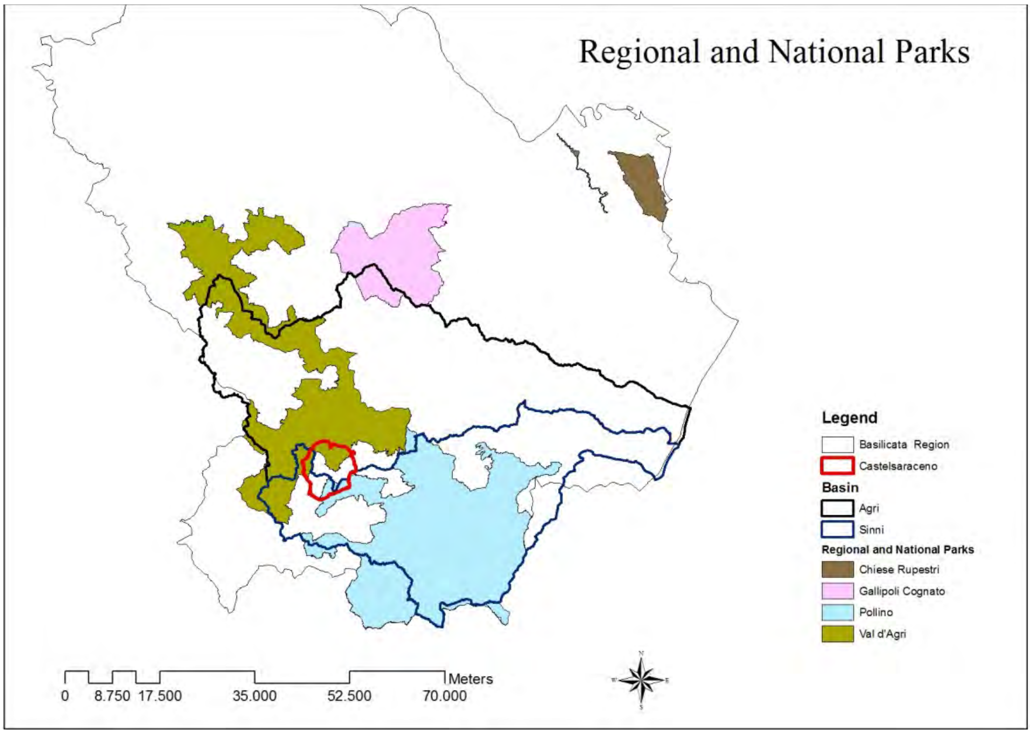



**Figure 49: Location of Castelsaraceno in relation to the two National parks.**

### 5.1.2 Topography

Castelsaraceno stands at 916 m (Figure 48) with an altimetry low of 675 m (Acqua di San Giovanni) and high of 1,861 m (summit of Mount Alpi). The area is bordered to the north by Mount Raparo (1,764 m), which offers protection from northerly winds, to the south by Mount Alpi, Mount Armizzone and Armizzoncello, to the west by Pietra Marina Castelveglio, to the north-east by a wide valley and to the east by a horizontal line of mountain ranges which includes the peaks of Tuppetto and Mount Asprella.

The territory of Castelsaraceno covers two hydro-geological basins, the larger Agri river basin (ADB Basilicata, 2013) and the smaller Sinni river basin (ADB Basilicata, 2013 - Figure 49). The Sinni river basin presents predominantly mountainous and hilly morphological characteristics. The highest peaks in the territory are situated along the western and south-western border of the basin, one of which is Mount Alpi (1,892 m) and part of the Castelsaraceno territory is made up of an area with Mesozoic mountain series made of: siliceous limestone strata with intercalations of marl and clay with varying thickness (Calcari with selce Auct.); alternations of polychrome and radiolariti siliceous argillaceous rocks in thin strata (Scisti Silicei Auct.); silciferous and siliceous argillaceous stone ("Galestri" Auct.). The area is also characterised by severe erosion and diffuse landslides. As for hydro-geological characteristics of the territory, this part of the basin is

[1] Calanchi (badlands) are a type of terrain with clay-rich soil, typical of the Basilicata region, characterizing most of its internal hilly areas.

characterised by a calcareous system and a dolomitic system with high permeability, which explains the presence of large aquifers.

### 5.1.3 Geology and Soils

The municipality of Castelsaraceno is situated in the Apennine mountain chain whose tectonic units derive from the complete inversion of basins, separated by platforms, formed following the tectonic extension of the middle and late (Rhaetian) Triassic period (D'Argenio et al., 1973). The paleo-geographic domains have originated from Mesozoic tectonic units that constitute the Apennine Chain (tectonic units that are overlapping from Miocene epoch). From West to East stands the Liguride unit formation, resulting from the deformation of the Tethys oceanic domain, which stands above the Apennine platform. In turn, this unit lies tectonically above the sediments of the Lagonegrese basin, characterized by numerous folds and over thrusts. The Sicilide and Irpine units emerge more frequently in the front portion of the chain. The Sicilide Units mainly consist of shale and severely deformed marls, whilst the Irpine Units are characterized by silico-clastic sediments, which record the progressive deformation of the Apennine chain (Figure 50 and Figure 51).

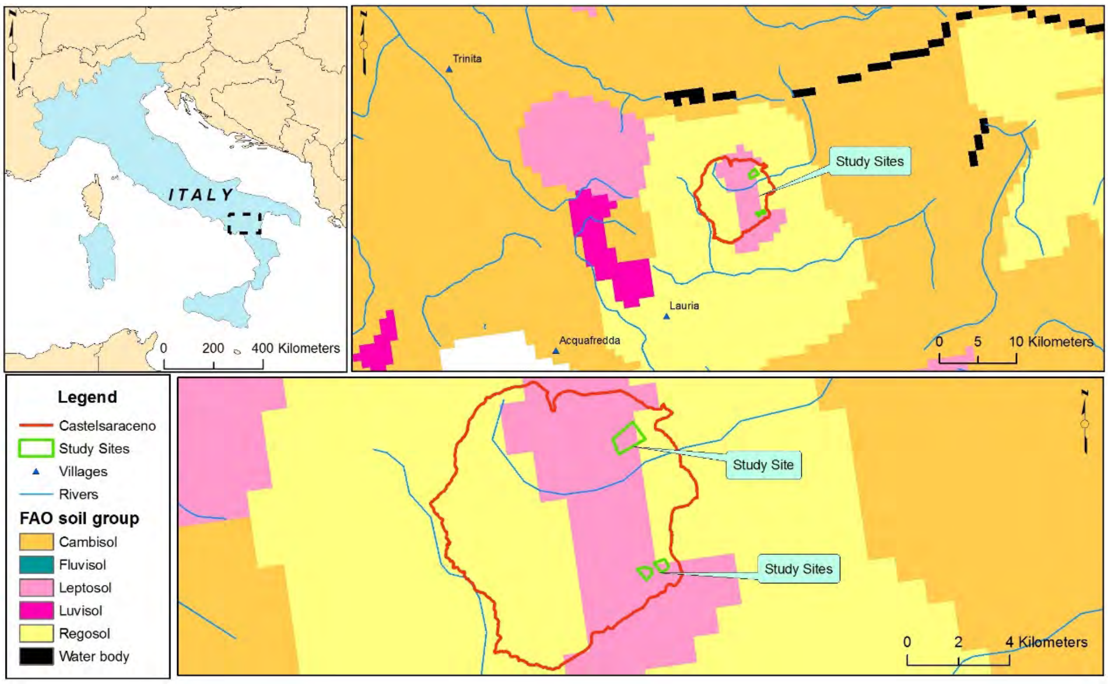



**Figure 50: Soil groups according to the FAO classification in the Study Site (Source: JRC).**

Castelsaraceno also lies within one of the most complex areas of the Southern Italy Apennines. In fact this area has the typical southern Italian Apennine alignments NW – SE and N – S with also the directions W – E and WNW – ESE which characterise the structures of Northern neighbour Calabria region. The basin of the river Agri also presents predominantly mountainous morphological characteristics and is home to Mount Raparo (1,764 m), which is characterised by limestone, dolomites, calcareous debris in strata and slabs–in places intensely fractured or with section formations of cataclastic rock. This area is also characterised by frequent landslides.

The carbonates formed between the late Triassic epoch and the Tertiary (Neocene) period in an area of the platform span between the Liguride domain and the Lagonegrese Basin (D'Argenio et al., 1973). They separate the complex into three units, characterised by sequences of varying thickness and facies and are therefore found in different paleo-geographic positions within a large area characterised by carbonate sedimentation. Mount Alpi is a limestone massif situated in the South-West of the Lucano Apennines. The chain is made up of a large Mesozoic carbonate sequence, around 1,000 m in facies, on which stand two distinct Neocene cycles. The oldest formations are limestone, dolomitic limestone and well-stratified dolomites passing to calcilutites (cement rock) with intercalations of oolitic limestone in higher layers. This sequence from the middle Jurassic - Lower Cretaceous epoch forms the backbone of Mount Alpi.

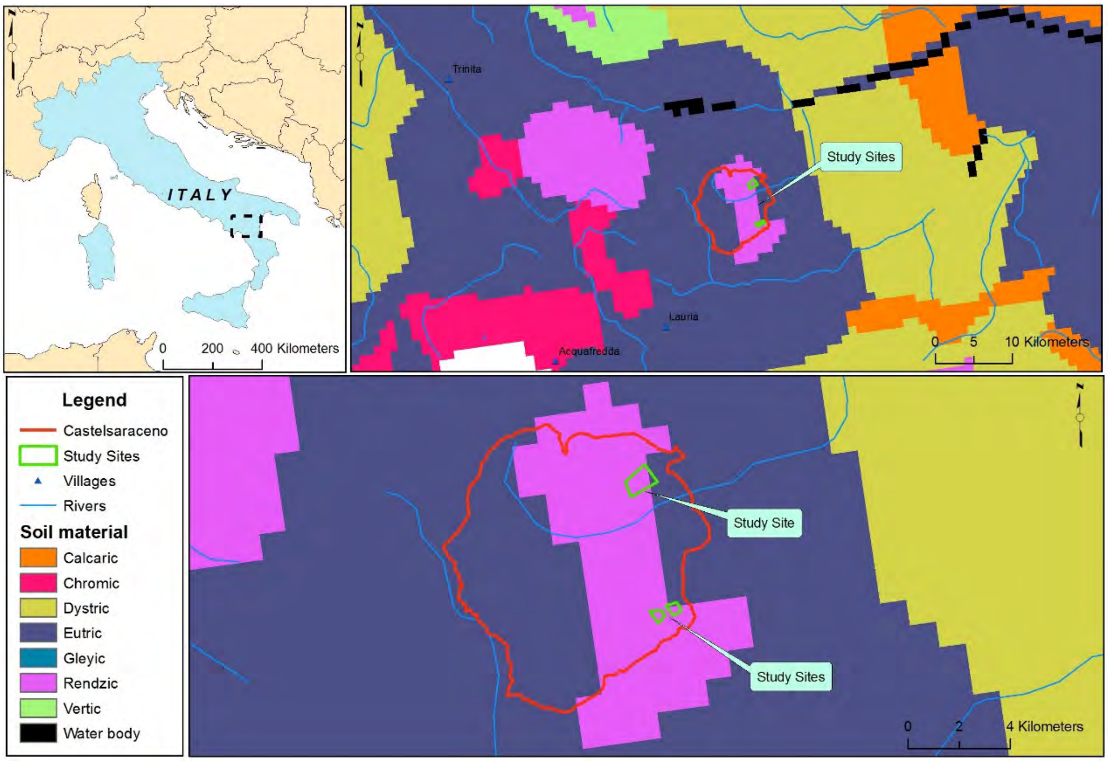



**Figure 51: Categories of Soil Materials (WRB) in the Study Site (Source: JRC).**

The following soils are present in the Castelsaraceno area (Basilicatanet, 2013):

- In hilly and mountainous areas with Mesozoic and Tertiary limestone rocks chalky soils are found;
- In the Apennines and anti-Apennine reliefs with tertiary sedimentary rocks such as marl sandstone and clay flysch there are high mountain marly soils and soils from central reliefs with rugged morphology;
- On the surfaces of the Bradanica trench with Pliocene deposits (fluvial deposits) soils of sandy hills and conglomerate rocks of the Basin of St. Archangel are found together with soils from floodplains.

### 5.1.4 Land Use

The analysis of vegetation cover for the Study Site (Figure 52) shows the most representative unit to be that of broad-leaved forest. Only a small part of the surface is instead dedicated to agriculture and discontinuous urban fabric. Between the 1990s and the year 2000, land use remained more or less the same with the majority of the territory covered by broad-leaved forest and land principally used for agriculture with natural vegetation and an absence of non-irrigated arable land and sclerophyllus vegetation, mixed forest and bare rock.

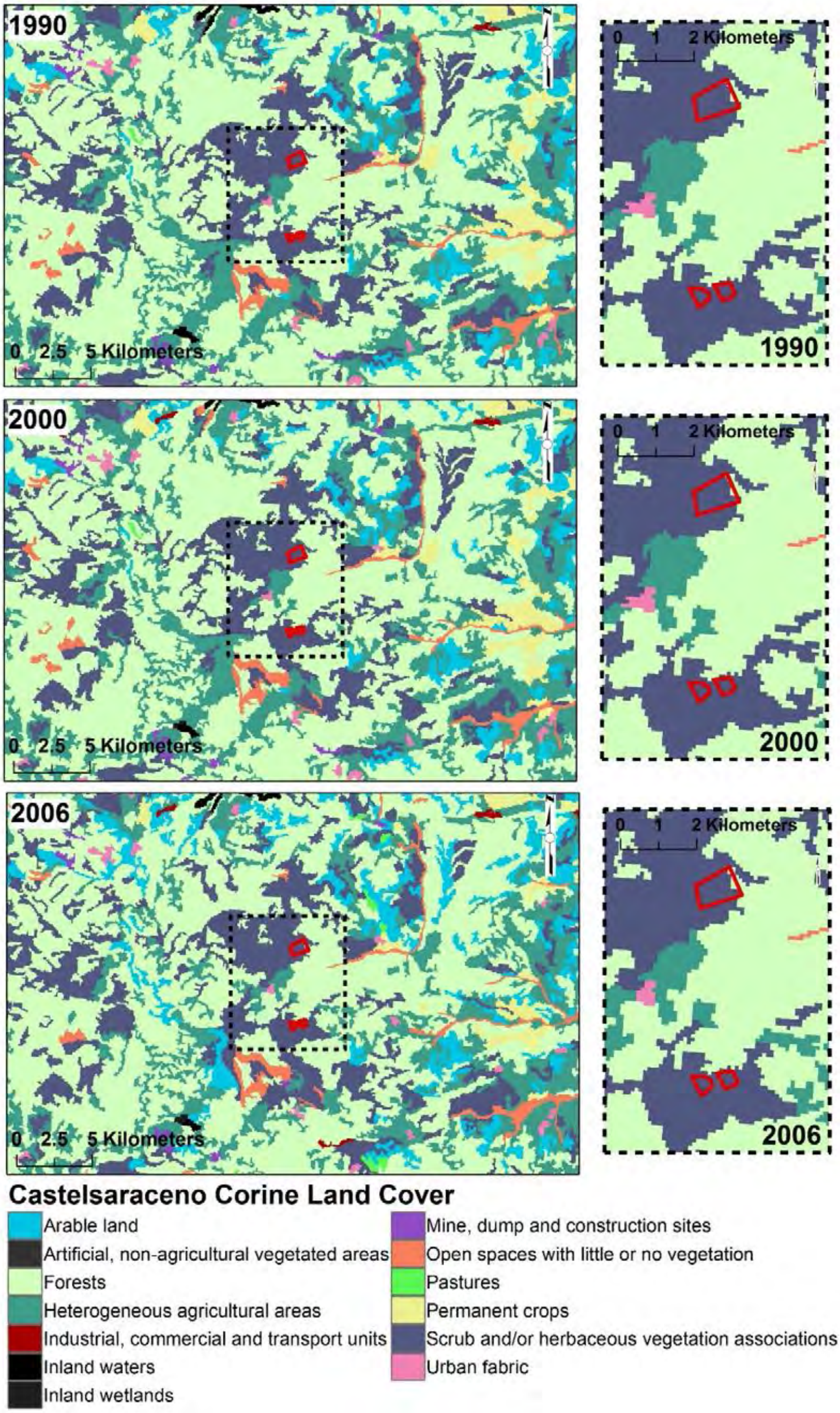



**Figure 52: Land use in the Study Site (Source: CORINE, JRC).**

After 2000, the area underwent substantial changes, to a large extent due to the significant reduction of population because of the continuing rural exodus affecting this area lacking in vital infrastructure and also in part due to the shift away from farming and towards occupations in other economic sectors. Land dedicated to traditional agricultural practices and self-sufficiency farming covers a limited area of Castelsaraceno and is concentrated in the area within the Park of Pollino and in the Sinni river basin; a large part of the territory is, instead, covered by natural grassland and broad-leaved forest. Land cover under transition is noteworthy and, as Figure 53 clearly shows, there has been a progressive encroachment of pastures towards woods and shrubland as well as variations in the use of Utilised Agricultural Area.

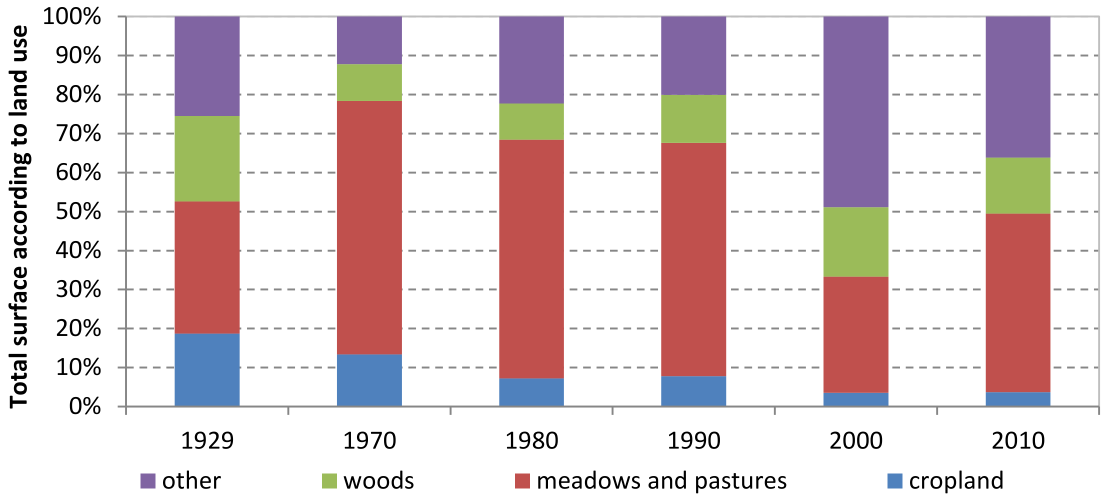



**Figure 53: Composition and variation of UAA. Data from Agricultural Census (ISTAT 1929, 1970, 1982, 1990, 2000, 2010).**

### 5.1.5 Climate

Using the Köppen climate classification, Castelsaraceno is characterised by a humid temperate climate – aridity index De Martonne - (ARPAB, 2006) with around 68% of rainfall during winter months and 15% in summer months. There is a difference in annual precipitation levels between the Agri and Sinni river basins. The Agri basin registers a range of precipitation between 900 mm and 1,700 mm a year. The Eastern areas of the basin, however, show lower levels of at just 200 mm a year. The Sinni river basin and the South-West area instead, have precipitation levels of between 900 mm and 1,300 mm a year whilst the NE areas just 200 mm a year. The municipality of Castelsaraceno has very high levels of rainfall. The data from the Castelsaraceno Meteo Station (850 m) from 1921 to 2011, infilled with with the E-OBS dataset (Haylock et al., 2008) shows average rainfall at around 1,290 mm a year or about 108 mm/month (Figure 54), nevertheless, there has been a slight decline in monthly rainfall over time.

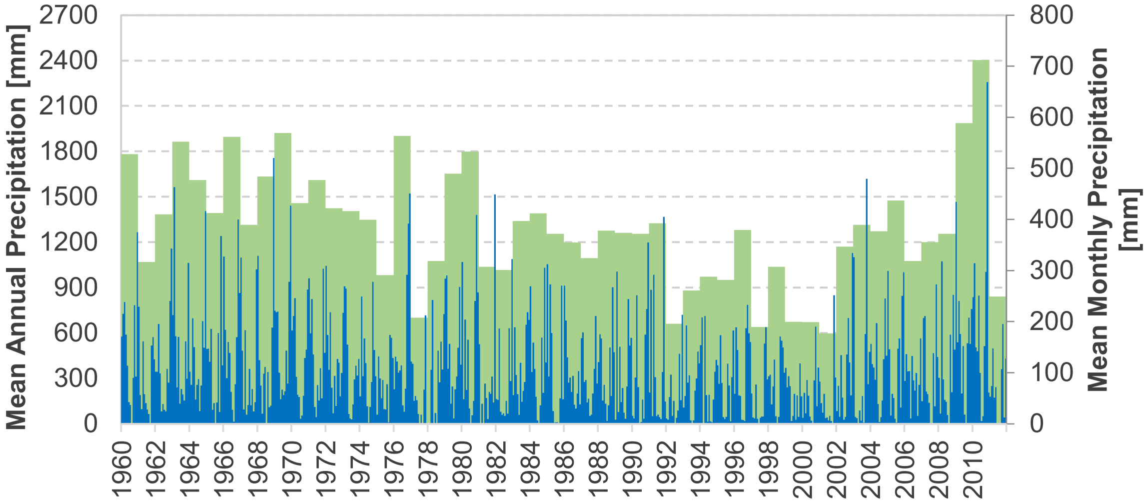



**Figure 54: Mean monthly (blue) and mean annual (green) precipitation measured at Castelsaraceno.**

The average temperature in winter months is 4.2 °C with humidity at 76%, whilst summer month's average temperature is around 22 °C with humidity at 56%. Average annual temperatures in both basins are more or less stable at between 12 °C and 15 °C. The NW areas of the Agri basin have an average temperature of 16-17 °C as does the eastern areas of both basins. The Sinni basin, however, shows average temperatures of 12-15 °C in 80% of its territory. Figure 55 shows the mean monthly temperature at the Study Site as it was estimated from the E-OBS dataset (Haylock et al., 2008). For the available record, temperature shows a significant upward trend of about 0.5°C per decade with an annual mean of 9 °C. Nevertheless, it is possible that this trend is part of a larger oscillation and that the past two decades have been at the warm part of the cycle. The potential evaporation for the Study Site using the E-OBS dataset and the Blaney-Criddle equation (Blaney and Criddle, 1962) is estimated at 1,230 mm.

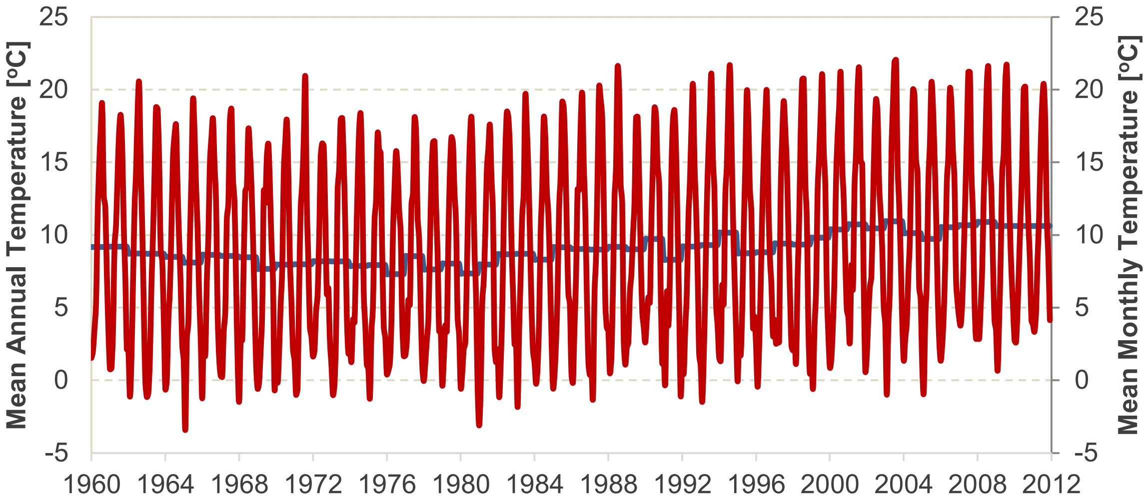



**Figure 55: Mean monthly (red) and annual (blue) temperature at Castelsaraceno derived from the E-OBS dataset and corrected for bias.**

### 5.1.6 Hydrogeology

Castelsaraceno straddles two hydro-geographic basins (Figure 56), the Agri river basin and the Sinni river basin. Both basins are similar in terms of hydrology. In fact, both are characterised by significant numbers of springs, high precipitation levels and higher minimum and maximum flow rates than other basins in the region. In terms of stratification and structure, the calcareous-dolomite complex of both Mount Alpi and Mount Raparo are characterised by high permeability and so contribute to the size of the aquifers.

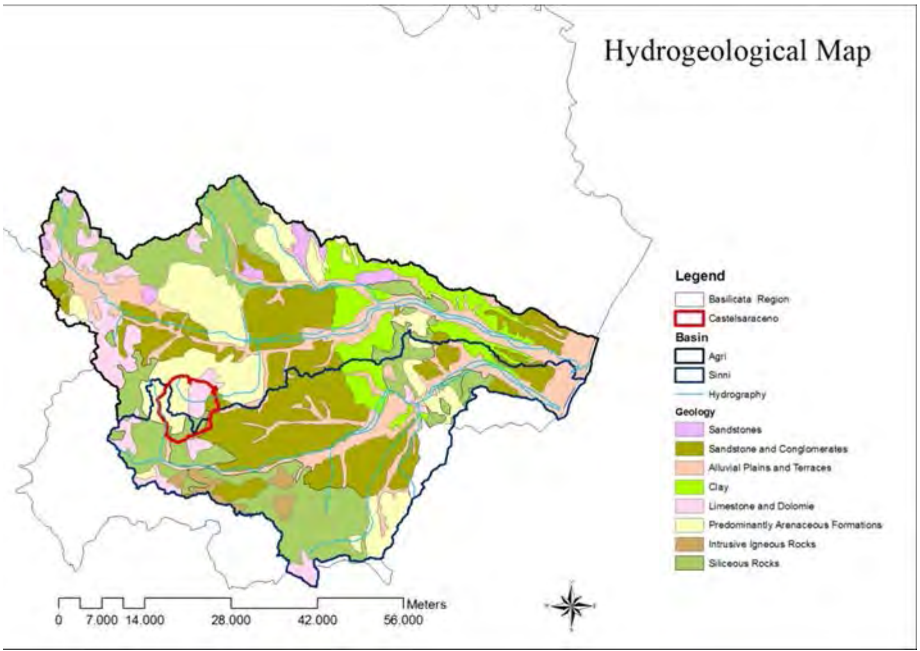



**Figure 56: Hydro-geological map of territory within the Agri and Sinni basins in the Castelsaraceno municipality.**

The Sinni basin receives water flow from Mount Alpi, whose springs - La Calda with average flow rate equal to 280 l/s and Caldanella with 18 l/s- provide Sinni with constant water flow (ADB Basilicata, 2013). The water flow from Mount Raparo (with the spring Varco Laino with average flow rate of 154 l/s and Prastiolo with average flow rate of 55 l/s) feeds the river Agri (ADB Basilicata, 2013).

In terms of hydrography and geology in the area there are:

1. High permeable calcareous complexes with high fragmentation and dolomitic complexes with medium to high permeability based on the state of fragmentation (hydro-structure M. Raparo).
2. Clay-marl complex with low to zero permeability.
3. Sandy-conglomeratic complex with medium-high to medium-low permeability based on the thickness and cementation of deposits.

### 5.1.7 Water quality

In 1997 the Basilicata Region started a program to monitor surface water, ground water and sea water quality as required by law (D.lgs 130/92) as part of the national SINA88 project (Sistema Informativo Nazionale dell' Ambiente – National System of Environmental Monitoring). The Agri and Sinni rivers, which maintain a modest degree of perpetuity storage to the presence of porous rock formation in their basin, have a generally good quality of water, thanks also to the relatively low numbers of industries and large urbanised centres (most inhabited centres do not exceed 5,000 inhabitants). Principal stress factors are agricultural activities and tourism sector activities. The value of dissolved oxygen and $BOD_5$, metal concentrates (Cd, Hg and Pb), total ammonia and non-ionized ammonia concentrations, values do not exceed limits set out in Dir. 98/83/EC (Regione Basilicata, 2000).

### 5.1.8 Main Ecosystems

***Flora***

In the past, agricultural areas were more extensive: signs of past agricultural use are still visible today, between the vegetation in rapid growth, but are largely abandoned or used by wild animals for pasture. Nowadays, four distinct areas can be identified; Mediterranean macchia on the plains extending to 400 m; sub-mountainous oak and chestnut woodlands (400-1000 m); mountain beech and conifer woodlands (the latter in the Pollino area: 1000-2000 m) and, finally, alpine pasture. The hilly part of the region with vast pastureland includes chestnut groves, vineyards as well as olive groves on lower land. The flora in the study area significantly varies with open shrubland and grassland plains to termo xerophile and mesophile brush which have evolved in the area due to human induced impacts on the territory since ancient times (pasture and deforestation). Forest formations include (a) cerreta Malboschetto (forest of Cerris) and mixed plant communities of Turkey Oak and the Downy Oak degraded to differing degrees along the southern slopes of Mount Alpi and (b) Beech wood forests which stand at 1,200 to 1,750 m and cover the eastern, northern and western scope of the Alpi S.Croce formation.
Mountainous and hilly pastures are, instead, very diffuse and principally include:

*a.* Arid pastures with predominance of Eryngium campestre (Figure 57a), *Cynosurus cristatus, Ononis spinosa, Lolium perenne, Trifolium repens,* (*Pleum hirsutum, Cichorium intybus, Brachypodium pinnatum, Cirsium vulgare and, sporadically, Spartium junceum, Chrisanthemum leucanthemum, Inula viscosa), Dorycnium pentaphyllum*. The pastures are found between 1,000 and 1,400m and are relatively evenly distributed over the territory and have the physiognomic characteristic of *Cynosurus cristatus.* Pastures with clearings between watersheds occupied by beech forests and the summit area are physiognomically dominated by *Festuca* circummediterranea (Figure 57b) and Bromus *erectus.*

b. Open steppa populations, on eroded soils to a greater or lesser degree, with *Spartium junceum, Calamintha nepeta, Teucrium polium, Teucrium chamaedrys, Bromus erectus, Sideritis syriaca, Helicrysum italicum, Scabiosa crenata* and *Stipa* austroitalica (Figure 57c) to name just the most important species*.* In the locality of Pietra Longa and Tempa Carlone these groupings are dominated by large populations of *Quercus ilex rupicoli.*

c. *Sodaglie* (fallow and untilled soils) to *Pteridium aquilinum* (Figure 57d), in which *Carlina acaulis, Digitalis ferruginea, Centaurium erythraea* are found.

Largely diffuse are also:

d. Thermo-xerophilous bushes, linked to stages of degradation (or evolution) of Sesille Oak forests. In addition to *Quercus pubescens*, the bushy layer is essentially made up of *Prunus* spinosa (Figure 57e), Crateagus *monogyna*, *Pyrus amygdaliformis*, *Spartium junceum* and *Alnus cordata*. In the less arid areas: *Ulmus minor* with infiltrations of *Quercus cerris* and *Fagus sylvatica.*

e. Thermophile woods with prevalently *Quercus pubescens* and *Alnus cordata*, with *Carpinus orientalis* and *Pyrus amygdaliformis (*Figure 57f*)*, sometimes with conifers.

f. Mesophyll woods *Alnus cordata* and *Fagus sylvatica*, with *Quercus cerris, Acer pseudo-platanus, Acer campestre*, and underwood with meadows and areas of woodland plants (nemorali).

**Eryngium campestre**

**Festuca circummediterranea**

**Stipa austroitalica**

**Pteridium aquilinum**

**Prunus spinosa**

**Pyrus amygdaliformis**

**Figure 57*:* Typical vegetation types in the study area.**

Some areas, such as Mount Teduro and Tempa Carlone, have been reforested, almost exclusively with Pino Nero (Black Pine) species, which often did not produce the anticipated results and even after many years have generally produced extremely impoverished forest populations. A synoptic view of the vegetation health and the associated function of ecosystems reveals a slight upward trend since the 1980s.

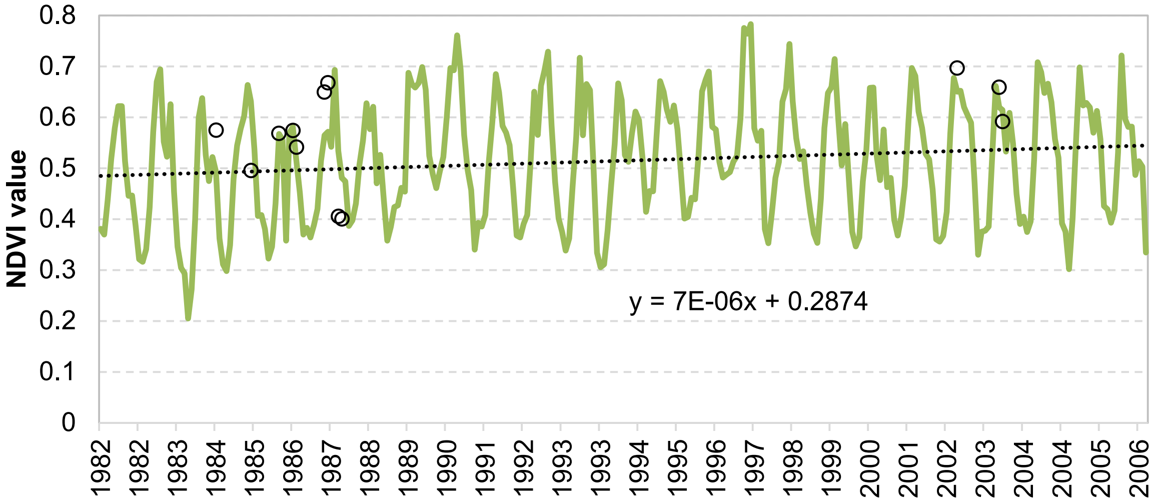



**Figure 58: Historical evolution of NDVI through time (green line using datasets from Pinzon et al., 2005; Tucker et al., 2005) corrected for bias using value from LandSat imagery (black circles).**

***Fauna***

The territory of Castelsaraceno has a large variety of fauna, as it is located between two large protected areas (the National Parks of Pollino and Val d'Agri-Lagonegrese). All principal species of mammals found in the southern Apennines are present in the local territory. Carnivores present include a discreet population of wolves (Canis lupus), wild cats (Felis silvestris) and others, which are found in the various water courses with good vegetation cover along the river banks. Rivers and humid environments represent an ideal habitat for various species of some migratory birds such as Black Storks (Ciconia nigra) and White Storks (Ciconia ciconia). Higher altitudes, above 1,500 m, are home to larger predatory birds such as The Golden Eagle (Aquila chrysaetos), the Peregrine Falcon (Falco peregrinus) and the Common Raven (Corvus corax). At slightly lower altitudes in the oldest forest areas the Great Eagle Owl (Bubo bubo) can be seen, whilst hilly areas are particularly inhabited with Red Kites (Milvus milvus) and the common Buzzard (Buteo buteo). In more humid areas, the Black Kite (Milvus migrans) and the Western march harrier (Circus aeruginosus) can be seen. Other significant population includes wild boar (Sus scrofa) and roe (Capreolus capreolus). Finally, aside the common European hare (Lepus europaeus), some groups of Apennine hares (Lepus corsicanus) native to central-southern Italy continue to thrive.

The principal source of income for local inhabitants remains agriculture and as such the local territory registers high levels of sheep and goat livestock farming and, to a lesser degree, cattle farming. Livestock composition has seen significant changes over the course of the last century, as three independent sources can verify (the Agricultural Census, Castelsaraceno town council register and the National Livestock Register). Data from the Agricultural Census shows that during 1970-1990 livestock numbers increased significantly, also in line with the increased standards of living and, consequently, the increase in pro capita buying power and demand for meat and dairy products. Nevertheless, mainly due to low competitive capacity of the Castelsaraceno livestock systems, also exacerbated by strictly enforced EU regulation, from the beginning of the 21st century, livestock numbers are in decline. The last decade shows a very dramatic reduction of livestock sector due to an accelerated dismantling in rural population. Table 3 and Figure 59 show a summary of the data from the National Livestock Register on numbers of animals currently present in Castelsaraceno, on monthly bases. The data shows an internal shift among different animal species (increase in the number of cattle which are less labor intensive and reduction of the number of sheep and goats that require more and continuous labor).

**Table 3: Variation numbers of livestock in Castelsaraceno (Agricultural Census, ISTAT 1929, 1970, 1980, 1990, 2000 and 2010. LU stands for Livestock Units.**

| Year | Cattle | var % | Sheep | var % | Goats | var % | LU* | var % |
|---|---|---|---|---|---|---|---|---|
| 1929 | 345 | | 1,453 | | 479 | | 637 | |
| 1970 | 428 | 24% | 3,452 | 137% | 1,223 | 155% | 1,136 | 81% |
| 1982 | 994 | 132% | 6,236 | 80% | 2,140 | 74% | 2,263 | 99% |
| 1990 | 720 | -27% | 7,876 | 26% | 2,317 | 8% | 2,264 | 0% |
| 2000 | 536 | -25% | 5,786 | -27% | 869 | -62% | 1,544 | -31% |
| 2010 | 699 | 30% | 961 | -83% | 133 | -84% | 865 | -43% |

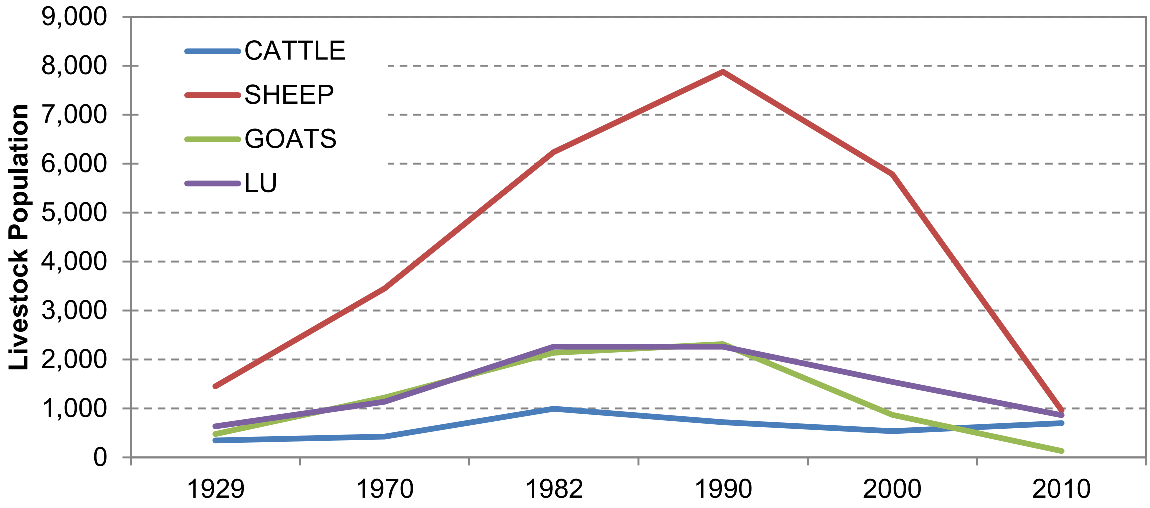



**Figure 59: Trend number of livestock years 1929, 1970, 1982, 1990, 2000, 2010 (ISTAT, Agricultural Census). LU stands for Livestock Units.**

***Selected Vegetation – soil system***

The "Piano dei campi" block shows well evolved and very deep soil, characterized by a powerful and reddish argillic (clayey) horizon. Soils in the block have loamy topsoil and a clayey-loamy soil in depth with coarse fragment ranging from common to abundant. They have moderately high permeability and good drainage. The dominant species is the *Stipa austroitalica*. The "Mount Alpi" block soils are loamy with umbric epipedon and variable coarse fraction content. Soils in the block show a loamy texture and a coarse fraction ranging from scarce to frequent. They are not calcareous and their pH is sub-acid on the surface and acid in the depth. The permeability is low and the drainage is good. The dominant species is the *Stipa austroitalica*. The "Favino" block includes deep clay and calcareous soils, with frequent coarse fraction on the surface and abundant in depth. Their permeability is low and drainage is good. They have derived mainly from the alteration of clayey marls (argillaceous marls). The dominant species is the *Brachypodium rupestre*. In degraded plots vegetation significantly changes, due to mismanagement of pasture. These ecosystems are characterized by lower presence and reduced quality of dominant species together with the disappearance of shrubs. This trend is observed in all three blocks regardless of their general but not substantial difference in soil parameters.

### 5.1.9 Socioeconomic status

The Basilicata region's abundance of rural features is ascribable to its geographic positioning in relation to the largest hubs of socio-economic activity. In fact the area's orography, together with its limited resources for agricultural activities, the lack of sustainable resources management (especially for forests), the isolation in which the area existed for many years and the diffusion of hydro-geological instabilities have produced a state of high environmental fragility in the region (Salvia, 2008). The rural economy has for centuries been the pillar of the local economy and the principal source of income for the population. However, over the last few decades the local identity has undergone significant transformation, a sign of an invisible break between local people and their territory (Muscolino, 2008). Castelsaraceno is a small rural community characterized by small farms. Scarce local resources make profitability very low in the agricultural sector which is affected by a structural weakness at a local level. Livestock farming is widespread in all local farms with small number of animals managed by family run businesses. The most common livestock reared are cattle, sheep and goats, given that the production and processing of milk is probably the most important agricultural activity in economic terms. The most common form of feeding livestock remains grazing which, as discussed previously, is often carried our without a rational use of the natural resources available, thereby causing serious damage to local sources of fodder crops. Shortcomings in the livestock farming sector in the local area can also be traced back to the advanced age of most local farmers, as well as their low levels of formal education. Moreover, problems arise from the fragmented structure of land, which does not facilitate the supply of food which the cattle need. Local sheep and goat meat is sold, usually by weight, to local traders or directly from farmer to consumers. The periods of greatest demand obviously coincide with holidays such as Christmas and Easter. Local milk is processed directly on farm and cow and goat milk is usually milked manually.

### 5.1.10 Timeline of events

Figure 60 shows a brief event timeline of the most important changes and milestones that occurred in the natural and social environment of Castelsaraceno.

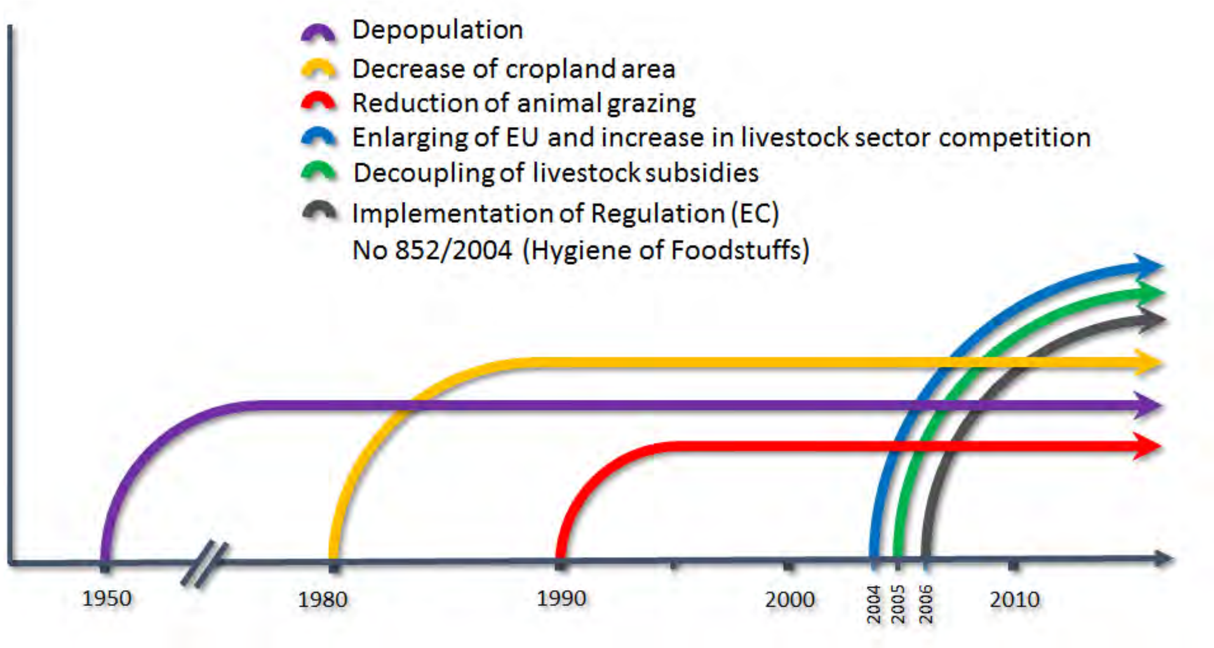



**Figure 60: Event timeline for Castelsaraceno since the 1970s.**

## 5.2 Main Causes of Land Degradation

### 5.2.1 Human induced Drivers

***Removal of natural vegetation, deforestation***

The Castelsaraceno Study Site has been inhabited since prehistoric times. Towards the end of the 8th century B.C. the arrival of the ancient Greeks in the region brought significant changes. The local area was re-organised around more sophisticated farming models, characterised by the division of land into small parcels, seen particularly on terraced land. The great agricultural expansion led to the beginning of deforestation with the now bare clayey slopes being subject intense erosion, which gave way to the first bad land formations (calanchi - badlands). Under Roman rule, large land estates prevailed, huge areas of the site were put to pasture and the systems of mono-cropping impoverished the soil and aggravated problems of erosion. In the $10^{th}$-11th century, the Byzantines and the Benedictine monks settled in the area due to its wealth of water sources and woodlands but carried out extensive deforestation in order to provide themselves with sufficient land for cereals crops, olive groves and grapevines (McCormick, 1998). The Napoleonic reign (1805-1814) saw a more intense landuse with increased deforestation and a further expansion in agricultural land which caused a severe aggravation of hydro-geological instabilities and the loss of fertility of soil on the slopes with serious negative impacts on sheep-farming which had been the most important activity in the region (Capodiferro, 2002). The deforestation in highland areas also affected the water courses thus resulting in extensive areas of swampy marshland at the river's mouth (Bevilacqua, 1991). Nevertheless, the extension of arable crop land co-existed with the conservation of livestock farming and sheep farming. Aristocratic land owners did, in fact, intensify the breeding of wild animals and resident species, set aside land for grazing and built permanent structures to house animals, while still extending arable farming practices. Even after the abolition of feudalism the large livestock famers continued to use state woods and pastures and integrated the use of arable land with trees in order to make a double income from the fruit of the crops and the trees, used as feed in pig farming (Fuccella *et al*., 2010). Subsequent legislation (no.927/1826) impeded deforestation by uprooting legalised the cutting of trees.

***Land management***

Regarding land management, Table 4 shows data from Castelsaraceno from agricultural census of 2010 for a total area of 7,400 ha. In that year the area registered a total of 111 farms, a reduction of around 71% compared to the year 2000 (386 farms). Data from the Agricultural Census (ISTAT) shows Castelsaraceno following the same trend in reducing farm numbers as seen in the primary sector all over Italy (see also Table 5). The most prevalent land use in the Study Site is currently meadows and permanent pastures, which make up around 70% of the Utilized Agricultural Area (UAA), whilst only 6% of land is used for arable crops. Around 80% of land in the local territory is common land owned by public bodies. These areas are generally public forests, pasture land, wooded areas, abandoned agriculture land, etc. An analysis of current legislation shows that town councils often fail to sustainably manage these land assets, with large areas in a state of abandonment or under an administrative role which leans towards a patrimonial management of lands (Bianchini, 2006). The first law regulating the division of state lands dates back to 1807. The law gave municipalities the control of the land and inhabitants lost their rights (Archivio di Stato, 1952). In the mountainous parts of the study area shepherds left their sheep to graze on unkept land, whereas in woodlands a sort of levy was imposed for the right to use the common land.

**Table 4: Agricultural Census, all area in ha (ISTAT, 1929, 1970, 1982, 1990, 2000, 2010).**

| Year | Cropland | Pastures | Woods | Other |
|---|---|---|---|---|
| 1929 | 1,384 | 2,509 | 1,623 | 1,884 |
| 1970 | 991 | 4,830 | 701 | 904 |
| 1982 | 533 | 4,530 | 685 | 1,652 |
| 1990 | 577 | 4,425 | 910 | 1,487 |
| 2000 | 263 | 2,203 | 1,318 | 3,616 |
| 2010 | 274 | 3,390 | 1,061 | 2,676 |

With regional law no. 322/1928, collectively owned lands were again re-structured and plans for re-forestation and better land management on the part of local administrations were introduced. However, the lengthy administrative process surrounding checks, favoured the unlawful occupation of lands by private individuals and led to the destruction of more forested areas and pastures. The poor management of collective lands led to the gradual reduction in utilisable surface area. In the 1960s and 1970s intervention began to restore collective pasturage in the South of Italy. To this end, rural houses, shelters and fencing were constructed, nevertheless with disappointing results that left new infrastructures abandoned.

Common lands only re-entered a framework of environmental safeguards and valorisation of agro-silvo-pastoral activities and local natural and human resources with Mountain Law no 97/1993 which authorised the regions to legislate in land management issues in the wider context of rural development. The Basilicata region regulated collective land management with law no. 42/1998 which entrusted third parties (farming and forestry cooperatives, individual farmers and farming associations, public and private consortiums) with the management of goods and/or services including the use of pasture on public owned land with wooded/grass cover. The law set out that the state body in ownership of grazing land would issue a card granting permission to farmers wishing to graze their animals on common lands, taking into careful consideration the maximum number of animals grazing that the specific land area could sustainably support. The applications for pasturage are annually forwarded to the state body in ownership of the land stating the precise area under application, the number of animals to be grazing per species and also general details of the applicant farmer’s activities. The responsible body then evaluates the maximum capacity for grazing of the site and denies or issues permission for grazing. The capacity of grazing livestock, expressed in Livestock Units (LU), for each area must take into account the current state of the grass cover. Pasturage of goats is permitted only on bare pasture land or on shrub land and in high-stand woodlands. Pasturage is forbidden on newly planted woodlands, woodlands under renovation or affected by fire. In the latter case pasturage is forbidden for at least one year after the fire. It is the responsibility of the farmer to supervise his livestock during grazing and un-supervised grazing is only permitted in fenced areas. Fires are not allowed in woods, and farmers must be vigilant to any fire risks and report any incidents immediately. Grazing land cannot be crossed by roads or lanes.

***Grazing management***

The Town Council of Castelsaraceno also set out regulations for grazing on common land in 1949 which changed the previous 6 to 12 months period of concession to a three month period. In reality the regulation was scarcely applied and from 1970 to 1991 as successive local administrations in Castelsaraceno failed to apply any regulations at all. Since 1991 pasturage regulations were re-introduced. Nevertheless, evidence shows that there has not been any type of checks or controls in place in this period on the number of livestock allowed to graze on the entire surface area of all municipal pasture land. Consequently, these lands were used un-evenly with areas characterised by reduced grazing pressure, where real grazing is lower than the potential estimated capacity through grazing methodologies (Argenti and Staglianò, 2001).
In 1999 Castelsaraceno Town Council passed deliberation no. 40 of 10/12/1999, in consideration of EC Reg. 207/92 (relating to methods of agricultural production compatible with environmental conservation and preservation of natural areas), which set out new regulations for pasturage on common lands. The regulation introduced several new elements: early pasturage applications to the Municipality should specify the locality under application, the period of grazing, number of animals per species and general

details of applicant farmers. These factors along with maximum grazing capacity of each site are carefully considered before authorizing exploitation. Evidence shows that after this deliberation, Municipal management of pasture land allowed only part of municipal pastures to be used by private individuals. In reality this did not help improve the situation of pasture lands in the study area, which had been in a state of gradual degradation since previous decades because of the absence of an effective system of regulation for use of common pastures and grazing capacities. Today there are still cases of areas with overgrazing and lower grazing.

### 5.2.2 Natural Drivers

According to the data collected it seems that natural factors had little or no influence on pastures degradation in Castelsaraceno area. Nevertheless, the long term SPI index (Figure 61) reveals that a drought spell in the 1990s could have increased pressure on the ecosystem. Regarding the Aridity Index (Figure 62), the area displays little signs of weather related aridity or humidity deficiency. Nevertheless, a spell of decreased precipitation seems to briefly change this regime between 1990 and 2000, later to be corrected by wetter years after 2007.

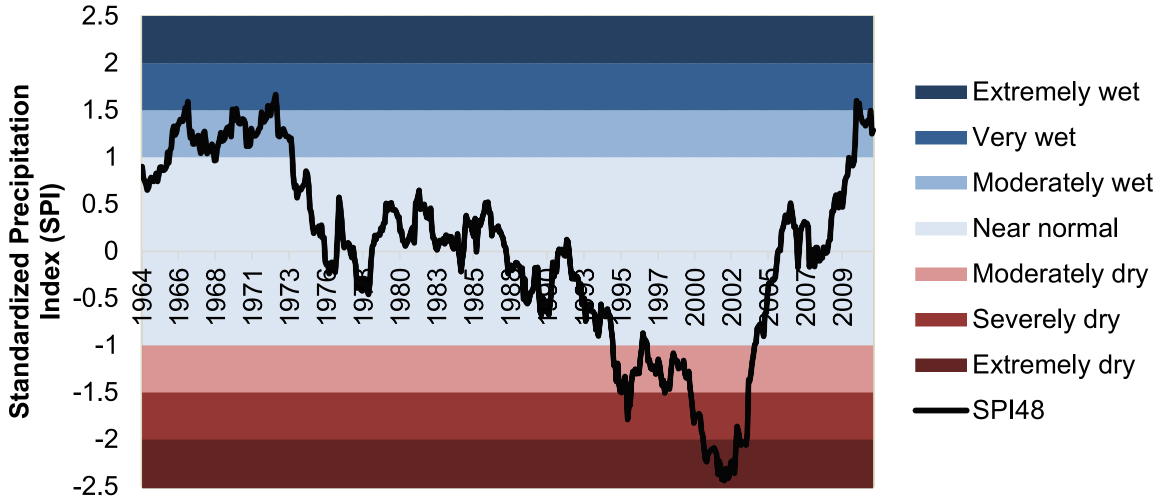



**Figure 61: SPI 48 estimated for the period 1963-2002 for the area of Castelsaraceno.**

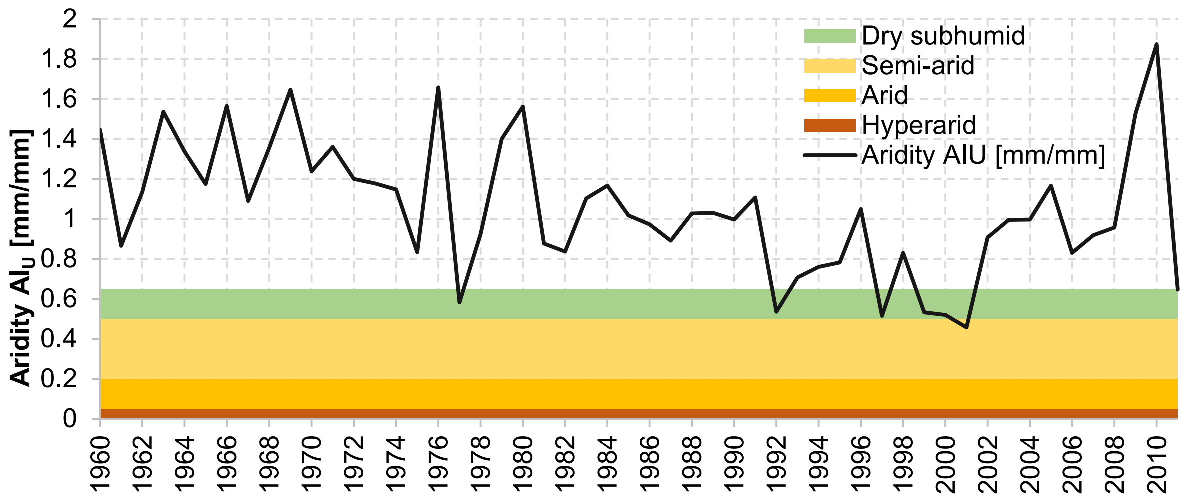



**Figure 62: Aridity estimated for the area of Castelsaraceno.**

### 5.2.3 Indirect causes

One of the greatest threats to the Castelsaraceno Study Site is depopulation (Figure 63). Negative demographic trends can play a key role in accelerating processes of degradation, causing reduced guardianship and increased abandonment of land which have serious environmental and cultural knock-on effects. Castelsaraceno, a township with a total surface area of 74.3 $km^2$ had a population of 1,480 in 2010, that is 250 less that in the year 2000, 540 less than 1990 and a staggering 961 less than in 1980 (ISTAT). The low population density which characterises the local area, around 20 inhabitants per $km^2$ together with the depopulation trend, can be attributed to the area's geographic position and difficult morphology as well as its severe lack of infrastructure. The township's geographical isolation has inevitably affected the mind-set of the local people, who, while showing a strong sense of belonging to their town, struggle to form a collective identity which hinders the process of territorial cohesion that is essential for the implementation of any processes of development. The depopulation of the area is mainly caused by the out-migration of young people, often the most educated, who look for a way out from the difficult conditions in which the community lives. More specifically, the closure or reduction of schools, health centres, post offices, shops and the generally poor economy, are the factors that mostly affect migration towards larger, more economically active urban centers (Quaranta G., Salvia C., 2008).

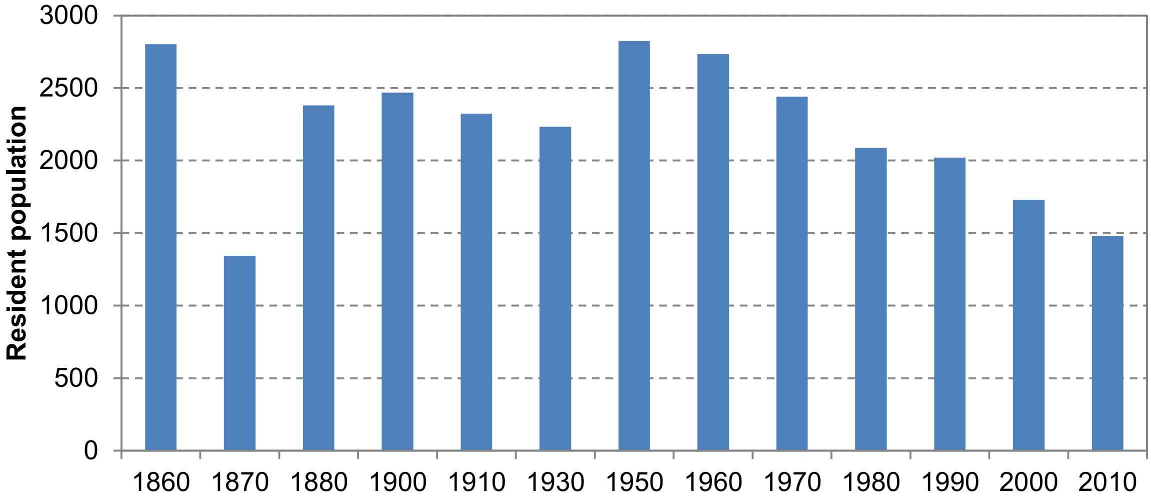



**Figure 63. Population trends in Castelsaraceno last 150 years (ISTAT).**

European agricultural policy is another factor that has impacted farms and conditioned the dynamic of livestock numbers and, consequently, the management of grazing. The first signs have been the application of the EEC Reg. 2078/92 and 2079/92 (confirmed also in the programming periods 2000-2006 and 2007-2013, together with measure 3.1 on organic farming). The entry into force on 1 January 2006 of the "Hygiene Package" (application of the EC Regulations n. 852/2004, 853/2004, 2073/2005, 2074/2005, 2075/2005 and 2076/2005) has permanently changed the EC rules on hygiene and official controls of foodstuffs. In this way, all Member States have the same criteria on the hygiene of food production and therefore hygiene checks are carried out according to the same standards throughout the European Community. Standardizing health standards has made the free movement of food products that are guaranteed as safe possible, which is a great benefit to consumers. However, the legislation has also introduced a series of stringent requirements for the livestock sector in rural areas which has resulted in a considerable number of producers leaving the sector, thus leading to huge reduction of farm units both at Castelsaraceno and Basilicata in the last decades (Table 5). Furthermore, considering the fact that the farms present are generally small, family-run farms based on traditional farming models which are not capable of supporting the rising costs of production and administrative and bureaucratic costs to comply with the new rules. The most common complaint among problems highlighted by local stakeholders is the cost of meeting hygiene standards (which amount to between 1,000 and 6,000 euro per year) that leads to the ceasing of many crop and livestock farmers.

**Table 5: Number of farm units in Castelsaraceno and Basilicata.**

| Year / Region | 1961 | 1971 | 1982 | 1990 | 2000 | 2010 |
|---|---|---|---|---|---|---|
| Basilicata | 100,586 | 91,873 | 82,424 | 79,387 | 75,929 | 51,756 |
| Castelsaraceno | 658 | 622 | 349 | 371 | 376 | 111 |

# 6 Messara Study Site (GR)

Responsible partner: TUC (2)

## 6.1 Definition of the Messara Study Site (GR)

### 6.1.1 General information

The Messara basin encompasses an area of 611 km$^2$ located in the central-south area of Crete (Figure 64), about 50 km south from the Prefecture capital, Heraklion, and constitutes the most important agricultural region of Crete. It is also the site for the Minoan palace of Phaistos and the Roman city of Gortys. The Messara Valley has remained rural with a small population of almost 45,000 inhabitants. In the Messara valley, the surrounding hills and mountains as well as elements such as Phaistos ruins, are strong landmarks, among the many that make Crete famous for its landscape and nature (Stobbelaar et al., 2000). Although human induced changes have affected the landscape (Rackham and Moody, 1996), agriculture predominates in the area, thus being a staple to the local economy. The Messara Study Site for CASCADE is comprised of plots around the villages of Pompia and Perion (Figure 64).

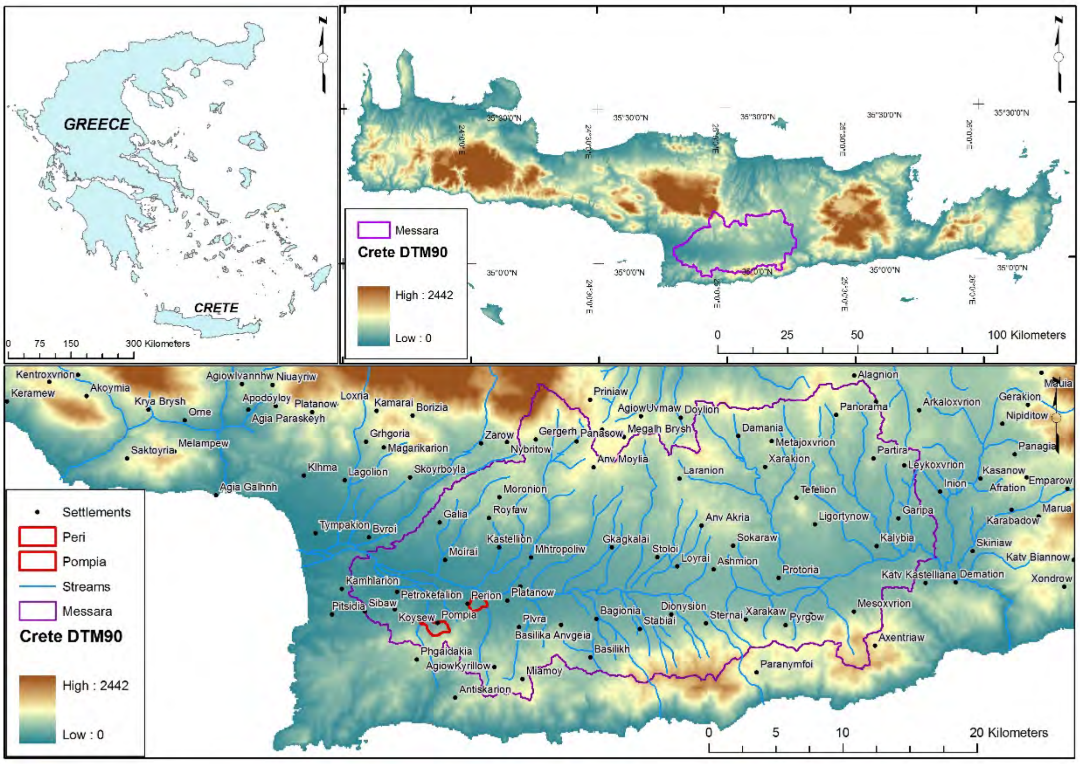



Figure 64: Study area – Messara valley.

### 6.1.2 Topography

Messara comprises of a plain with East-West orientation, about 25 km long and 5 km wide, with a total area of 112 km$^2$, hedged with mountains on the north and south sides (Figure 64). The basin can be conceptually divided in two hydrological catchments: the Geropotamos-Festos and the Anapodaris-Xarakas. The geomorphological relief is typical of a graben formation and the surface drops within 15 km from 2,454 m in Psiloritis

Mountain to 45 m at Festos. The Geropotamos River with a westward direction and the Anapodaris River with an eastward direction drain the homonymous catchments. The catchment area of the northern slopes is 160 km$^2$ while the southern slopes constitute a catchment area of 126 km$^2$. To the north, the divide varies from 1,700 to 600 m from west to east, with the highest point being part of the Ida mountain range (peak at 2,540 m) (Croke et al., 2000). The Asterousia mountain chain lies in the south and rises 600 m in the west to 1,200 m in the east. The Messara Valley covers an area of 398 km$^2$ within the watershed, with a mean altitude of 435 m. Charakas catchment lies at the east part of the Valley and Geropotamos River flows to the west, forming the catchment of Phaistos, where it meets a constriction at an outlet 30 m (Croke et al., 2000).

### 6.1.3 Geology and Soils

The plain area of the two catchments hosts the largest alluvium aquifer system of the island, extended in an area of 216 km$^2$. Topographically, the Messara basin is characterized by a flat basin morphology modified by river terraces and alluvial fans (Peterek and Schwarze, 2004). The Messara valley, defined by the inner Messara graben zone, is an alluvial plain mainly composed of quartenary deposits. The Plain is covered mainly by quarternary alluvial clays, silts, sands and gravels with thickness from a few meters to 100 m or more. The soils in the plain belong to the order of Entisols (Stobbelaar et al., 2000). In the north, the Valley is bordered by a hilly area of silty-marley Neogene formations, whereas in the south schist and limestone Mesozoic formations are dominant (Figure 65).

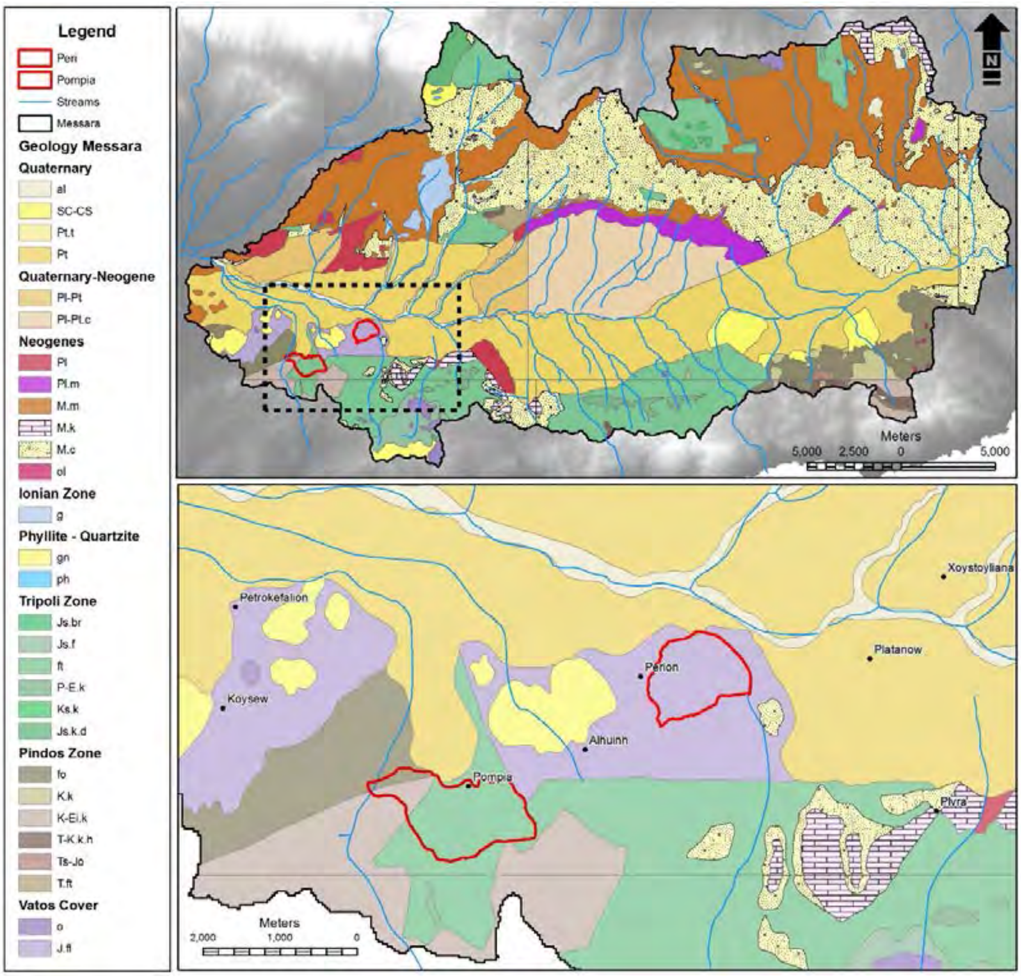



**Figure 65: Simplified hydrogeological map of Messara basin (Source: IGME).**

According to the JRC WRB Soil Geographical Database (excerpt shown in Figure 66), dominant soils in the basin are cambisols (north slopes), luvisols (south and north-east slopes) and fluvisols (center of the valley). According to the same source, calcaric soils are dominant across the basin with the exception of the east part where soils are chromic (Figure 67).

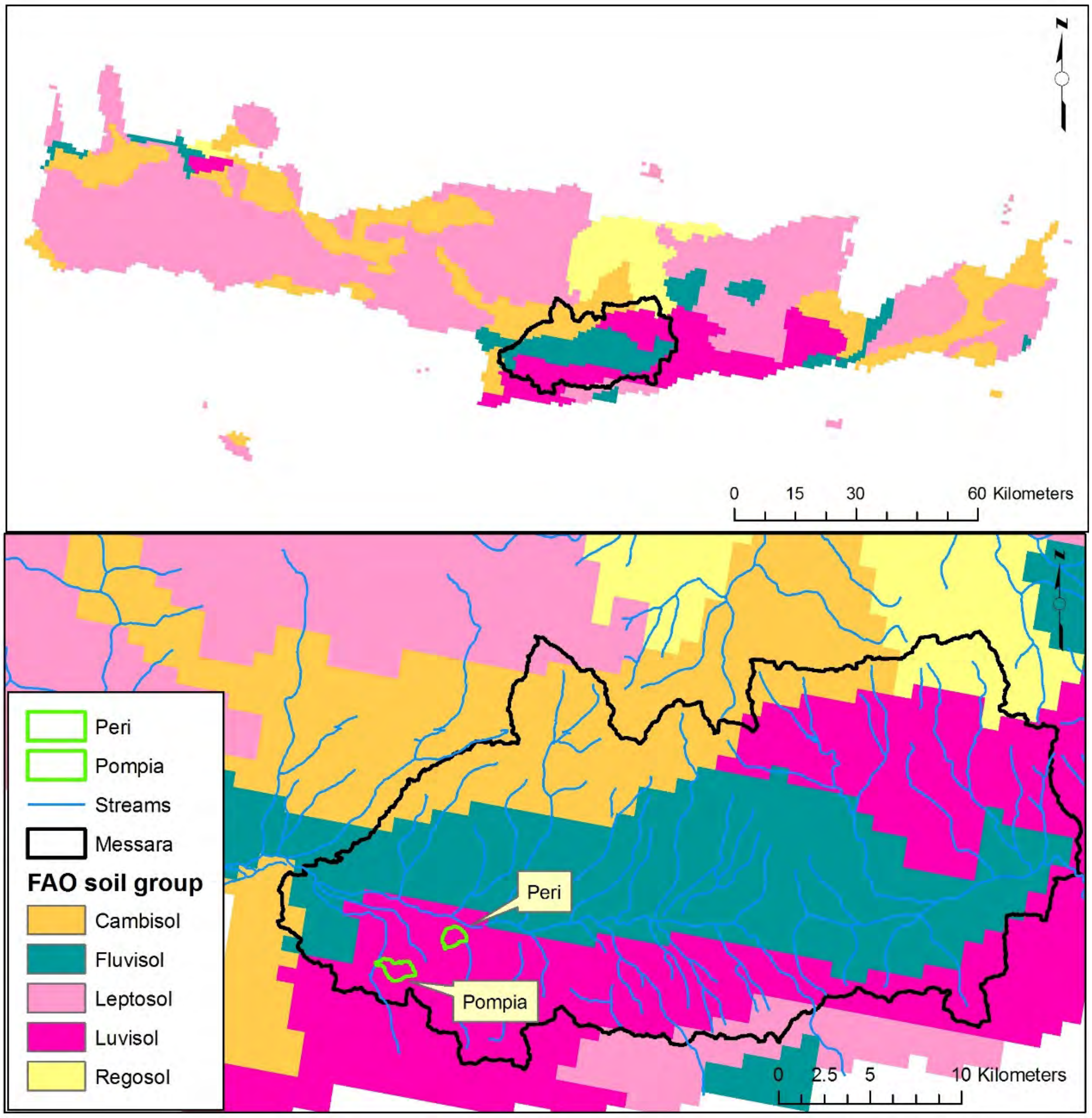



**Figure 66: Soil groups according to the FAO classification in the Study Site (Source: JRC).**

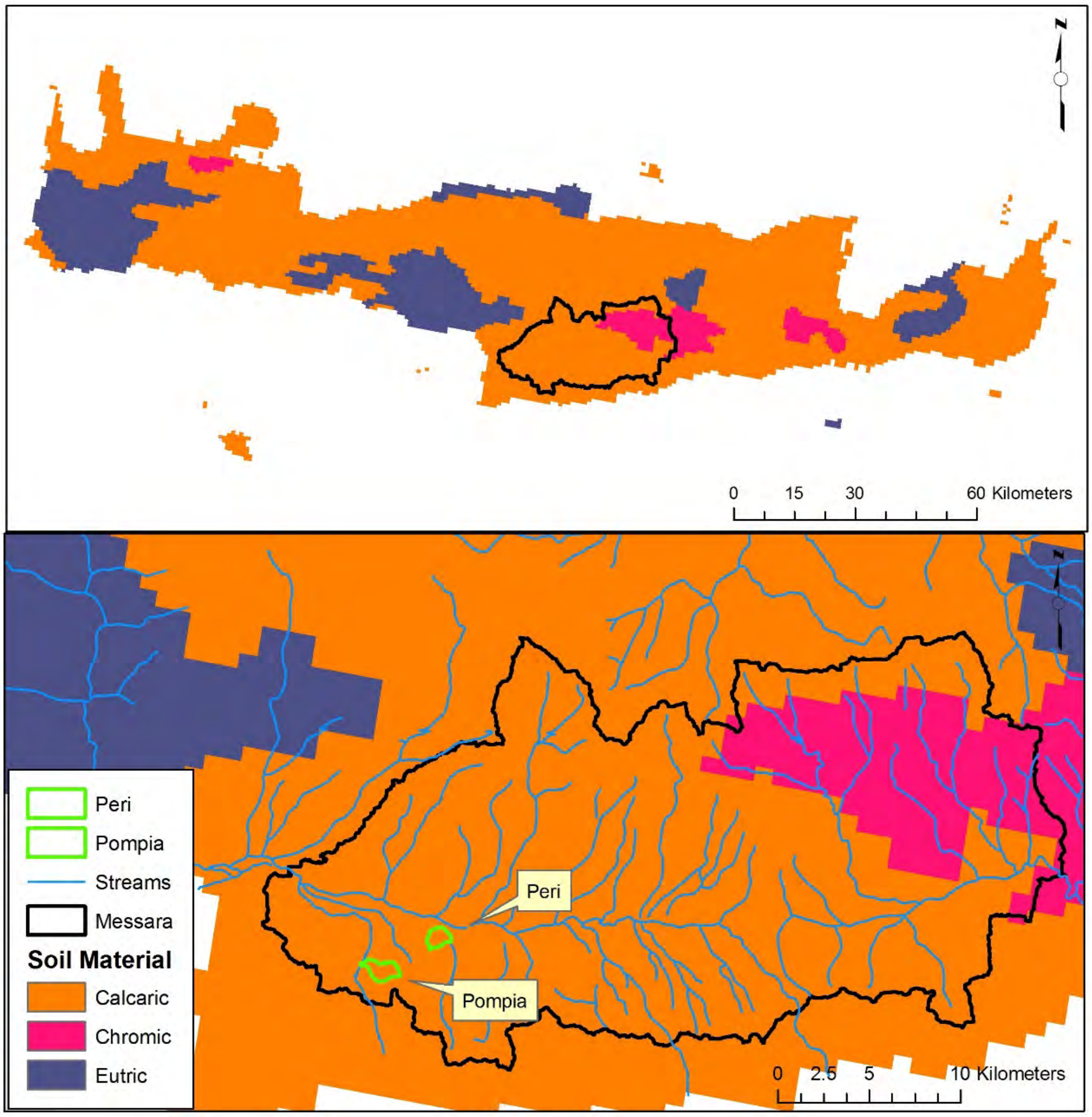



**Figure 67: Categories of Soil Materials (WRB) in the Study Site (Source: JRC).**

### 6.1.4 Land Use

About 250 km$^2$ of the total Valley area of 398 km$^2$ are cultivated. The main land-use activity is olive growing (about 175 km$^2$) with some grape vine cultivation (40 km$^2$). The remainder of the cultivated land is used for vegetable, fruit and cereal-growing as well as for livestock grazing (higher grounds). The vines and about half of the land area under olives are drip-irrigated (Vardavas et al., 1997). For the period of 1984-1997 cereals covered an area of 25 km$^2$, vegetables 16 km$^2$ and grape vines 26 km$^2$, while the area of the watered olive trees increased from 38.5 km$^2$ in 1984 to 110 km$^2$ in 1997 (Tsanis and Apostolaki, 2008). As shown in Figure 68 and verified by aerial photographies since the 1940s, the Study Site shows little change in terms of landuse. The only significant transition can be observed at the Pompia area, where “open spaces with little or no vegetation” actually represents burned area. From a total of 2.1 km$^2$, about 0.8 km$^2$ are within the Pompia Study Site and since then have been fully recovered and transformed to scrublands. Actually changes not clearly documented in CORINE include the intensity of exploitation for each landuse, as well as the extent of sealed and urban areas.

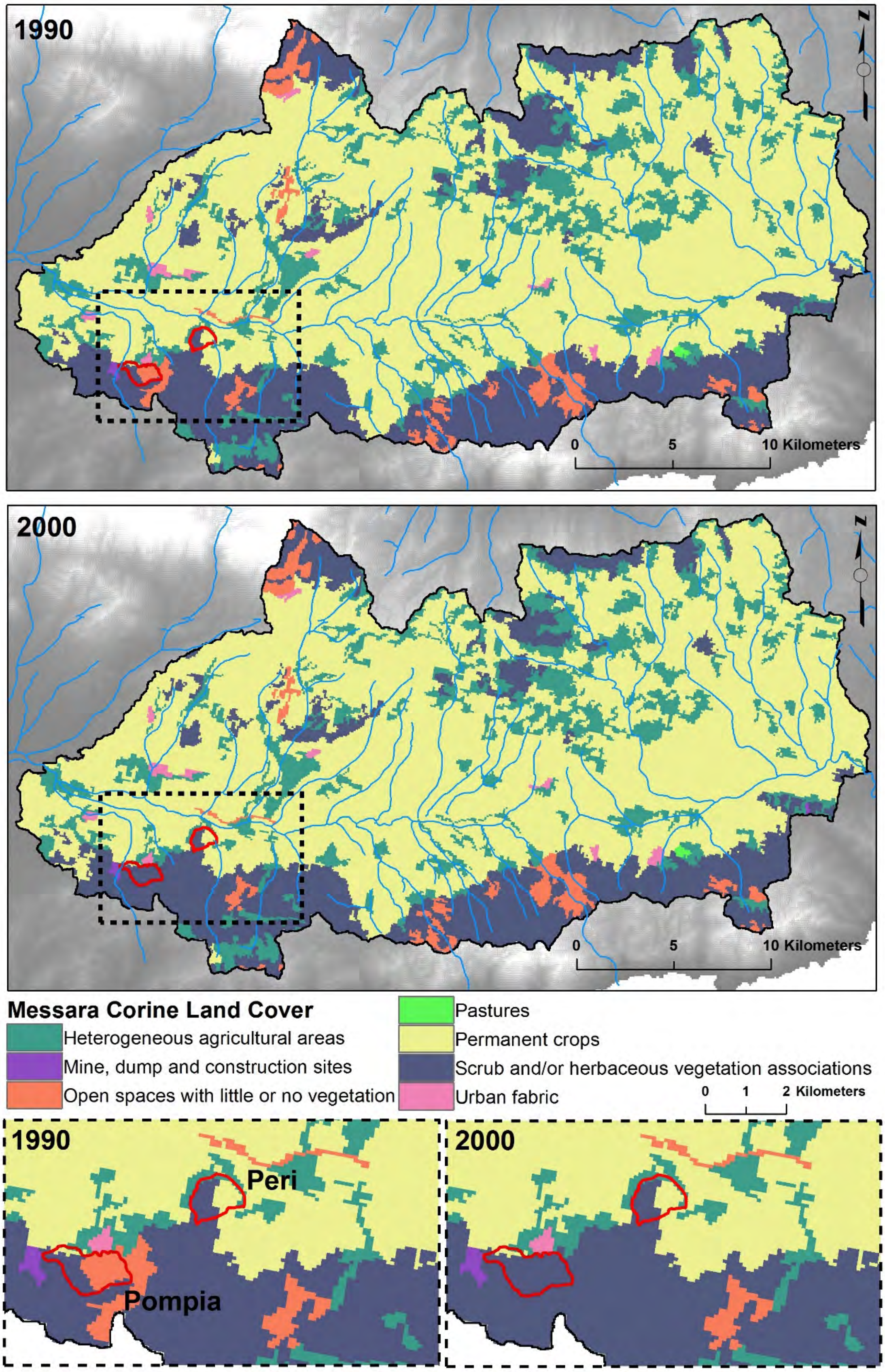



**Figure 68: Land use in the Study Site (Source: CORINE, JRC).**

### 6.1.5 Climate

Messara Valley's climate is classified as dry sub-humid according to UNCED (Paris Convention on Desertification, 1994) definitions and its hydrological year can be divided into a wet and dry season (Tsanis and Apostolaki, 2008). Crete has a typical Mediterranean island environment with about 53% of the annual precipitation occurring in the winter, 23% during autumn and 20% during spring while there is negligible rainfall during summer (Koutroulis and Tsanis, 2010; Naoum and Tsanis, 2004). Although the Valley receives on average about 650 mm of rainfall per year, it is estimated that about 65% is lost to evapotranspiration, 10% as runoff to sea and only 25% goes to recharging the groundwater store (Croke et al., 2000). Rainfall increases with elevation from about 500 mm on the plain to about 800 mm on the basin slopes while on the Ida massif the annual precipitation is about 2,000 mm and on the Asterousian Mountains it reaches 1,100 mm (Tsanis et al., 2006). The maxima of mean monthly precipitation generally occur during winter with the exception of Central South part of Crete (South of Messara Valley) where the maximum mean monthly precipitation is in November and September (Koutroulis et al., 2010). Figure 69 shows the mean monthly precipitation measured at the Pompia meteorological station. For the available record, precipitation shows no significant trend and remains stable at an annual rate of 504 mm.

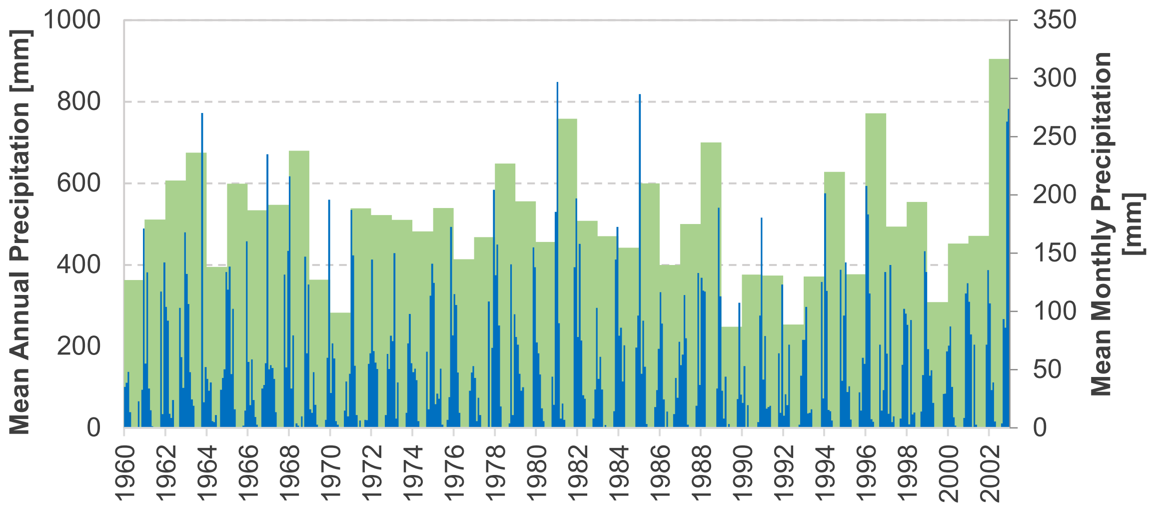



**Figure 69: Mean monthly precipitation (blue) and mean annual precipitation (green) measured at Pompia.**

The average winter temperature is 12 °C while in the summer it is estimated at 28 °C. Figure 70 shows the mean monthly temperature at the Study Site as it was estimated from the E-OBS dataset (Haylock et al., 2008). For the available record, temperature remains stable at an annual mean of 16.6 °C. Relative humidity in winter is about 70% whereas in the summer it reaches about 60%. Pan evaporation is estimated at 1,500 ± 300 mm per year while the winds are mainly north-westerly. The potential evaporation in the area is estimated at 1,300 mm per year (Croke et al., 2000) and for the Study Site it was estimated at 1,575 mm using the E-OBS dataset and the Blaney-Criddle equation (Blaney and Criddle, 1962).

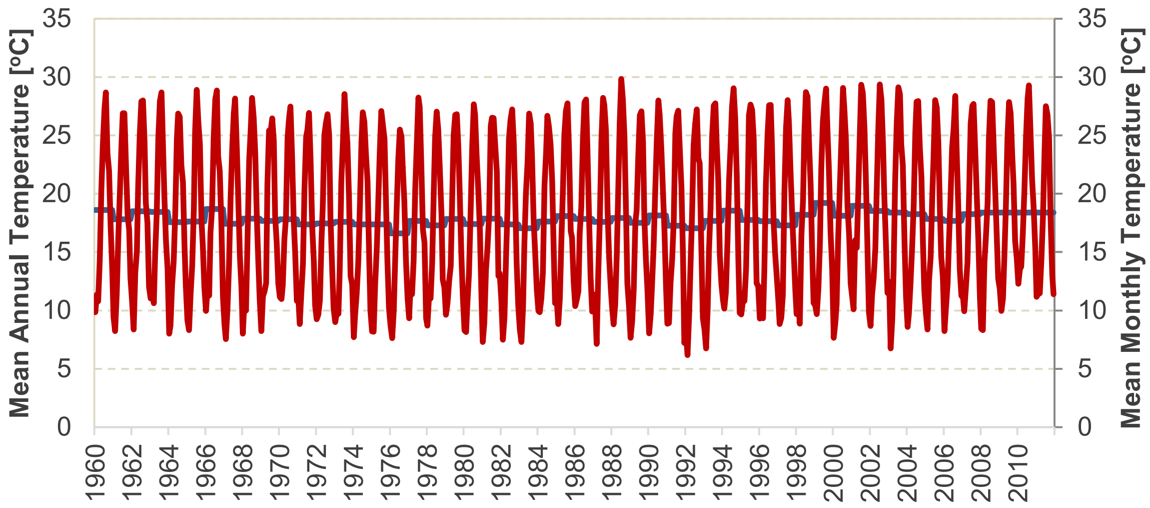



**Figure 70: Mean monthly temperature (red) and mean annual temperature (blue) at Pompia derived from the E-OBS dataset and corrected for bias.**

### 6.1.6 Hydrogeology

The plain area of the two catchments hosts the largest alluvial aquifer system of the island, containing several aquifers and aquicludes of complex distribution and properties. The inhomogeneity of the Plain deposits gives rise to great variations in the hydrogeologic conditions even over short distances. Soil porosity decreases with depth below surface (Tsanis et al., 2008) in a range of 0.05–0.13. The Neogene sediments and flysch are both characterized by a relatively high runoff while a small part of the mountain area is occupied by karstic formations characterized by negligible runoff and high infiltration. Groundwater is an important natural resource of the Messara Valley, as it is the main source of irrigation and domestic supply. Groundwater levels are highest in March or April with long recessions until recharge occurs in winter (Tsanis et al., 2006). Lateral groundwater outflow is small compared with the vertical groundwater outflow. In the area, 845 registered wells operated in 2004 and in 2007 their number was estimated at 1,400 (Kritsotakis and Tsanis, 2009) causing a drop in the water table of as much as 45 m due to overexploitation. Figure 71 shows the variation of groundwater recharge and discharge with areal precipitation of the Messara basin. This figure shows that during wet years there is high recharge and low discharge, while the opposite occurs during dry years. It is also obvious that during the 1990s the discharge increased rapidly due to the intense groundwater withdrawal for irrigation purposes.

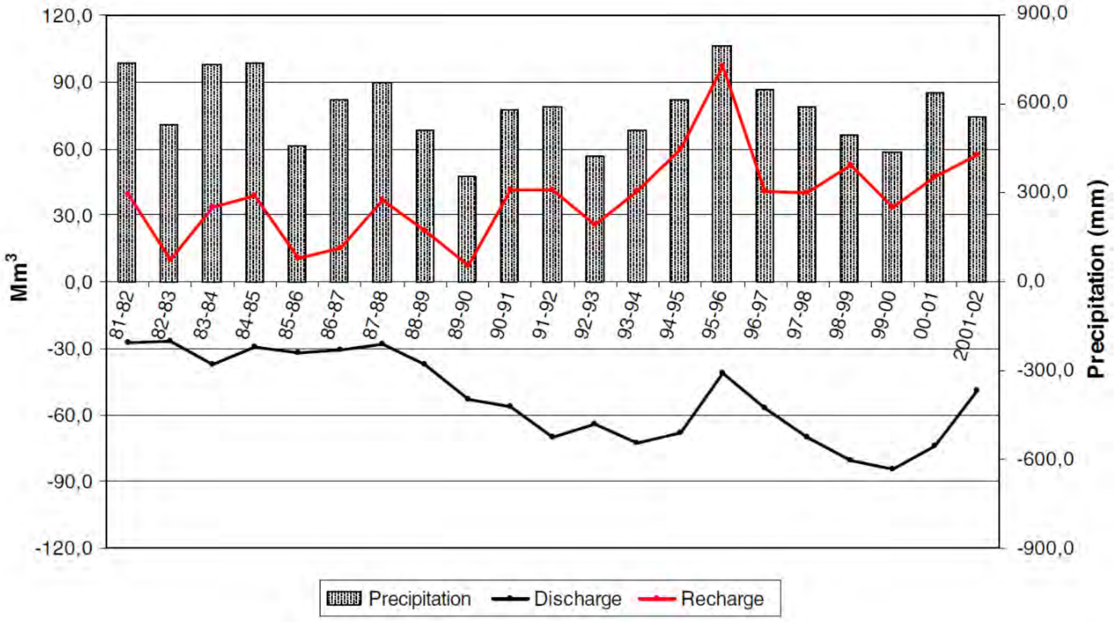



**Figure 71: Precipitation and groundwater recharge and discharge for the period 1981-2002 (Tsanis and Apostolaki, 2008).**

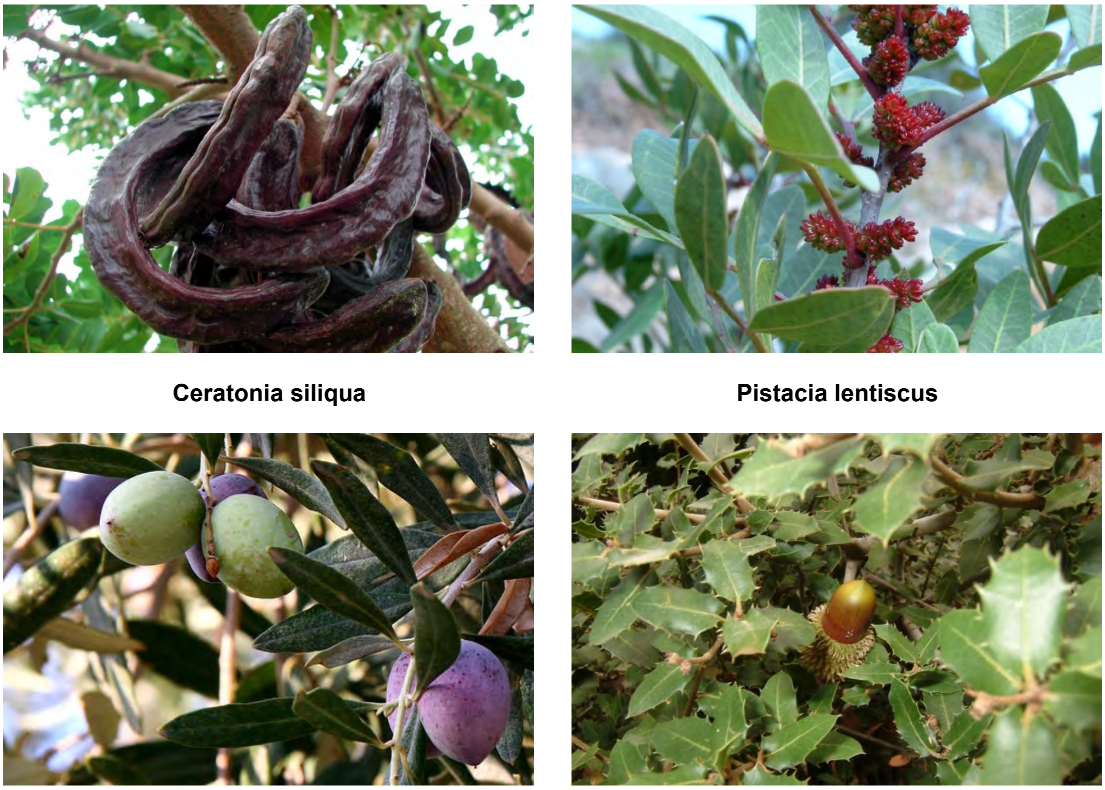
### 6.1.7 Water quality

Criteria given by the water Framework Directive (WFD) and the Dir. 98/83/EC were used for the quality assessment of groundwater and surface water collected from Messara and Anapodaris basin (Kritsotakis and Tsanis, 2009). It was concluded that concentrations of physico-chemical parameters, heavy metals, conventional pollution parameters, total organic carbon and phenols as well as pH and electric conductivity values of karstic aquifer groundwater samples do not exceed the Parametric Values given by European Community (Kritsotakis and Tsanis, 2009). In shallow alluvial aquifers, water quality parameters, such as nitrate and sulphate, evidencing contamination sources such as fertilizers, wastewater disposal sites and olive-mill factories were estimated for groundwater samples contents over the drinking water guidelines given by Dir. 98/83/EC. Notwithstanding the fact that during the last 50 years pesticides were used in the area, only the aminomethylphosphonic acid (AMPA) which is the major metabolite of glyphosate, was detected in the groundwater samples in values close to the parametric one. Finally, anthropogenic contamination due to agriculture, with high values of sulphate and chloride, was detected through the analysis of surface water (streamflow).

### 6.1.8 Main Ecosystems

***Flora***

There is no doubt that with some exceptions, Crete was covered with forest before Neolithic times. Today, there is no forest left in the region (Bottema, 1980) but the natural landscape is dominated by scrublands, the typical Mediterranean garigue (Stobbelaar et al., 2000). The most common and most characteristic vegetation type in the area met today is the evergreen maquis/phrygana. It is found predominantly from 0 to 600 m, but may reach about 1,000 m. Two major units are recognized (Bottema, 1980): a community with Pistacia lentiscus and Ceratonia siliqua is met in the lower zones and the coastal plains, always together with Olea europaea and Quercus coccifera, with Q. ilex, limited to altitudes between 300 and 1,000 m (Figure 72). Average percentage frequency of selected shrubs and herbaceous species are presented in Table 6. As many natural species in the area provide free fodder, especially in overgrazed areas such as the Study Site, the less palatable / poisonous plants such as Urginea maritima often survive and dominate the landscape.



**Ceratonia siliqua** **Pistacia lentiscus**

**Olea europaea** **Quercus coccifera/Q. ilex**

**Figure 72: Typical vegetation types of Messara basin.**

The Messara landscape has been in cultivation for thousands of years, leading to 30% of the flora of Crete being linked to agriculture and around 200 species being imported with agricultural systems from abroad (Stobbelaar et al., 2000). Two main agro-ecological zones occur in the region: the hilly zone, surrounding the plain, and the plain (Figure 64). Each zone displays different agro-ecological characteristics (Kabourakis, 1996) but also interacts with the other to the degree that it affects environmental variables such as water and fodder availability, soil preservation, fire hazard, etc. Since 1980, the marshes of the Messara valley have also been transformed to cultivated land (Stobbelaar et al., 2000).

**Table 6: Average percentage frequency of selected shrubs and herbaceous species along transects for 5 locations in Asterousia and 8 locations in Messara (adapted from Watrous et al., 1993)**

| | Spieces | Asterousia Mountains | Messara valley |
|---|---|---|---|
| Medium shrubs (0.5-2.0 m) | Lentisc (Pistacia lentiscus) | 10.4 | <0.1 |
| | Wild Olive (Olea europea) | 1.5 | 0.5 |
| | Spiny broom (Calicotomvei llosa) | 2.7 | 15.6 |
| | Cretane benus (Ebenusc retica) | 0.8 | 1.6 |
| | Jerusalems age (Phlomiss pp.) | 0.6 | 0.9 |
| | Sage (Salvia triloba) | 0.4 | 1 |
| Low shrubs, shrublets, and vines (0.5 m) | Thyme (Thymusc apitatus) | 13.3 | 18.9 |
| | Thorny burnet (Sarcopoteriusmpi nosum) | 3.9 | 5.6 |
| | Germander (Teucriumsp p.) | 1.8 | 1.4 |
| | Phagnalon( Phagnalong raecum) | 0.7 | 1.9 |
| | Everlasting( Helichrysumsto echas) | 0.4 | 3.6 |
| Grasses | Brome (Bromes pp.) | 50 | 52.8 |
| | Wild barley (Hordeumsp p.) | 6 | 31.2 |
| | Wild oat (Avena spp.) | 10 | 37.5 |
| | Hyparrhenia (Hyparrhenia hirta) | 16 | 21.2 |
| Legumes | Sainfoin (Onobrychsisp p.) | 24 | 18.8 |
| | Clover (Trifoliums pp.) | 20 | 37.5 |
| | Medick (Medicagosp p.) | 2 | 50 |
| | Birdsfoot-trefoil (Lotuss pp.) | 4 | 50 |
| | Horse-shoe vetch (Hippocrepis u.) | 8 | 28.8 |
| Daisies | Hawk's-beard(C repiss pp.) | 14 | 43.08 |
| | Hedypnois (Hedypnois cretica) | 34 | 13.8 |
| Lilies | Wild onion (Allium spp.) | 26 | 11.2 |
| | Asphodel (Asphodelus aestivus) | 22 | 25 |
| | Sea squill (Urginea maritima) | 4 | 37.5 |

A synoptic view about vegetation health and the associated function of ecosystems can be derived from analysis of archival and on-going sequences of NDVI. Figure 73 depicts NDVI change through time using datasets from Pinzon et al. (2005) and Tucker et al. (2005). New estimations from LandSat imagery (black points) at the exact locations of the Study Site were used to correct the global dataset for bias. This initial exploration of NDVI in the study area has shown no significant trend since the 1980s.

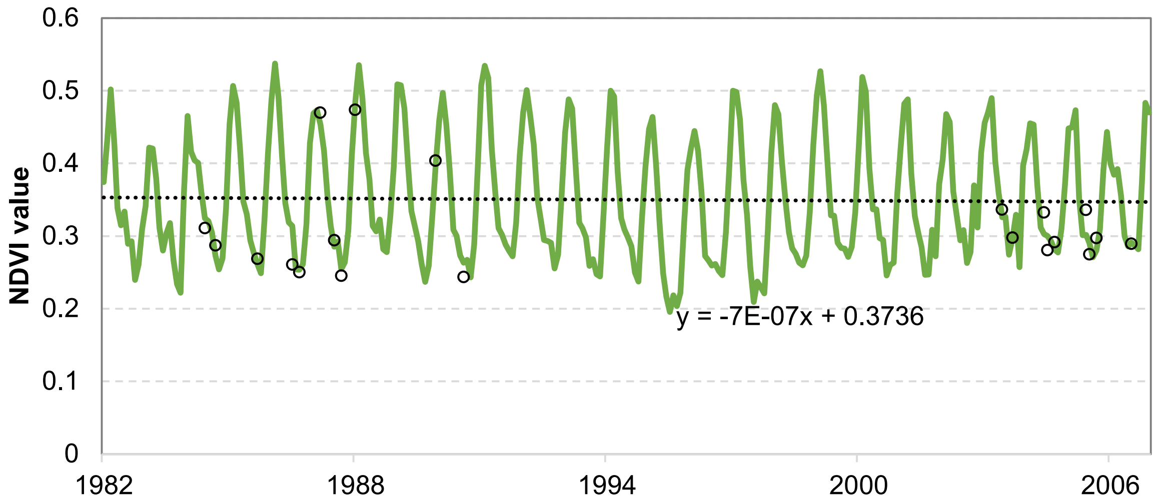



**Figure 73: Historical evolution of NDVI through time (green) corrected for bias using value from LandSat imagery (black circles).**

***Fauna***

The fauna in Crete is the result of a severe human-induced selection in favour of species belonging to the geographic and cultural universe of the human groups that immigrated to the islands, within which domestic livestock predominate (Troumbis, 2001). Rational grazing, the model developed for several millennia in Crete, was harmonized with the local biodiversity and contributed to its protection by preventing abandonment. The cultivation of olive trees on agricultural lands (lowland areas of Crete) has resulted in the gradual destruction of the natural environment and biodiversity. Today, the fauna has 2,500 members 180 of which are endemic. The dominant pastoralism model regarding hilly - mountainous regions (foothills) involves free grazing of sheep and goats. Traditionally animals were grazing in the fields and in the olive groves (Figure 74), and were used for transportation and land cultivation.

Studies on grazing-capacity (number of animals that can be supported per grazed area) are not available in Crete, thus causing pastoralists to increase herds to numbers that cannot be sustained by the pastures. When the nutritional needs of the animal population are not met, ultimately the shepherds are forced to deal with fodder costs. The use of fodder imported to Crete (mainly corn) forces animals to eat anything dry, as they have a cellulose deficit, without which their digestion cannot be sustained. For this reason they are often forced to eat tree bark etc. to meet their nutritional needs, thus causing even greater damage to the natural vegetation.

**Figure 74: Flock of sheep- passing through the agricultural area (Photo: M. Grillakis).**

Animal population in Crete reached 2,200mil. in 2000, and is now estimated to be around 1,700mil. In recent years (2007 to present), a 30% reduction of the animal population took place due to the doubling of the fodder price. On average, each producer has about 200-250 animals of which about 20% are goats. Figure 75 shows the change of livestock population since the 90s in the area around the Study Site of Pompia and Perion, at the foot of the Asterousia Mountains. The figures are based on surveys of sheep and goats in 12 neighboring municipalities from 1993 to 2008. Data has been divided according to the mean altitude of each municipality (over and under 250 m). Based on the livestock survey, livestock population in lowland, more urbanized and more touristically attractive areas is decreasing while highland population is increasing. In recent years, chances in livestock population are marginal.

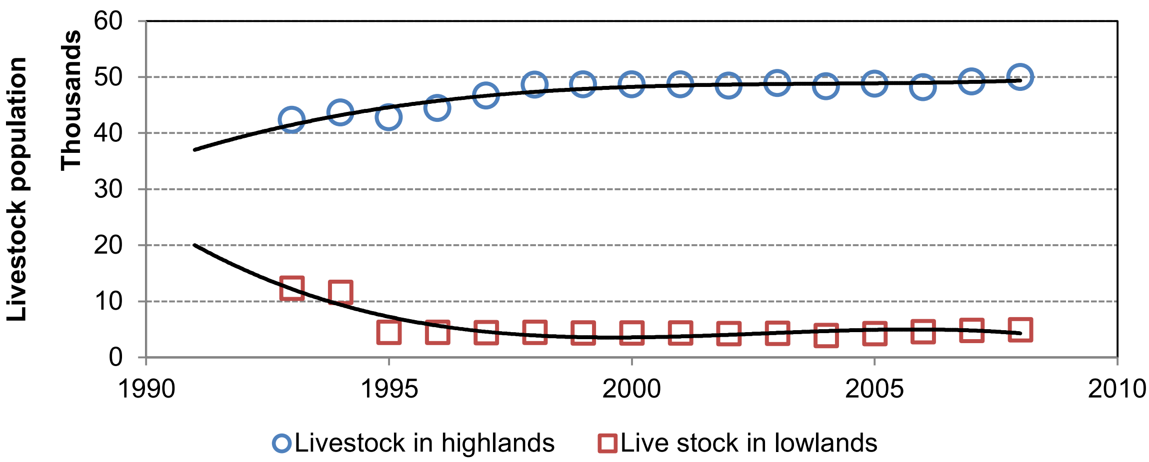



**Figure 75: Livestock (sheep and goats) population in the area of the Study Site. Based on data from Greek National Statistical Service.**

***Selected Vegetation – soil system***

The selected vegetation in the Study Site is Hyparrhenia hirta which is native to much of Africa, the Mediterranean and Eurasia. Lloyd and Moore (2002) describe the plant as a densely tufted, annual, or more usually perennial, grass, 0.3–1.5 m tall with awned, hairy, grey green spikelets carried in many pairs of racemes, in an open panicle and tough, dense bases sprouting from rhizomes. Each raceme has a leaf-like bract at the base and the inflorescence atop the wiry stem is a panicle of hairy spikelets with bent awns up to 3.5 cm long (Lloyd and Moore, 2002). The grass can grow in a variety of habitat types, in dry conditions, heavy, rocky, eroded soils, and disturbed areas. It grows on a wide range of soils from shallow sands to clays and floodplains (Smit et al., 1995), clay soils (Mentis, 1999), dolerite hills, disturbed and shallow soils (Smit et al., 1992). Grasses like Hyparrhenia hirta show a marked increase in flowering after fire events, but the herbaceous species are soon replaced by woody plants (Watrous et al., 1993). Coolati grass is a C4, usually perennial plant, however under good nitrogen conditions and in a Mediterranean environment it is not expected to be more productive than the cool season C3 plants (Cresswell and Prophet, 1985). Along a transect across the Western Messara (Table 6), the average percentage frequency of Hyparrhenia is 16.0% and 21.2% at Asterousias Mountains and Messara Valley, respectively (Watrous et al., 1993).

The soil in the Study Site is of average composition and is characterized as loamy and calcareous. It contains 30-50% $CaCO_3$ and moderate to low organic matter (0.8-1.2%). pH is neutral to slightly alkaline, between 7.6 and 8.5. This soil belongs to Luvisol. The mixed mineralogy, high nutrient content and good drainage of these soils make them suitable for a wide range of agriculture, from grains to orchards to vineyards. Luvisols form on flat or gently sloping landscapes under climatic regimes that range from cool temperate to warm Mediterranean. Figure 76 shows the soil texture estimated from soil samples in the Study Sites so far.

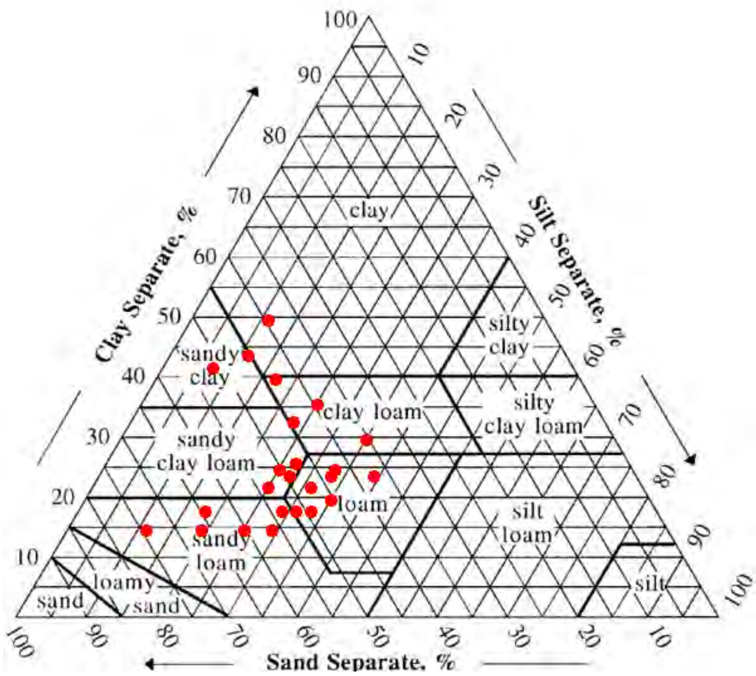



**Figure 76: Provisional soil texture in the Study Site.**

### 6.1.9 Socioeconomic status

The agricultural lands in the mountains of Greece are characterized by a decreasing population density due to socio-economic and political factors. This land abandonment, as a result of outmigration and off-farm employment, leads to less productive lands that are susceptible to environmental degradation (Petropoulou, 2007). In Messara, fields are usually scattered around the villages with the average farmer owning about 5-10 plots with an average farm size of 3.5 ha, while the average distance between the village and the plots is 3-5 km. This unprofitable system that obliges farmers to commute partly exists due to the Cretan heritage system, according to which all children receive a part of the farm, and partly due to the unwillingness to exchange fields. The island customs discourage land consolidation thereby leading to increased fragmentation and declining farm size. This custom can explain the high number of small land-parcels prevailing in the study area. Furthermore, most grazing grounds are not clearly defined as they can be both private and public and many make use of the law about acquisitive prescription allowing them to take ownership of land after 20 years of undisputed use. Both land tenure and taxation system appear to play an important role in the farm size. The cultural value system dictates maintaining the land ownership even during the absence of the owners who often return to cultivate them after retirement (Kassa et al., 2002).

Nowadays, Cretan agricultural practices mainly include monocultures, with olive groves and vines both in the hills and in the plain. Vine growing has become quite challenging, as it comprises intensive labor in contrast with the low prices in the market. Although excellent wines and raisins are produced, harsh global market competition, management and marketing problems, as well as the current economic crisis, cause profits to reduce significantly. Furthermore, olive oil is the main product of the island and at the moment the most profitable crop of the agricultural sector. In contrast to fresh products, olive oil does not need fast transport, but its price is also lowered on the saturated European market under the pressure of economic crisis while marketing problems have started to appear as well. This single-commodity approach makes olive growers vulnerable to market fluctuations (Stobbelaar et al., 2000). Economic crisis and the inability of pastoralists to purchase fodder have resulted in the abandonment of pastures and as a result the problem of overgrazing is indirectly solved with adverse effects.

### 6.1.10 Timeline of events

Figure 77 oulines a brief event timeline of the most important changes and milestones that occurred in the natural and social environment of Messara basin.

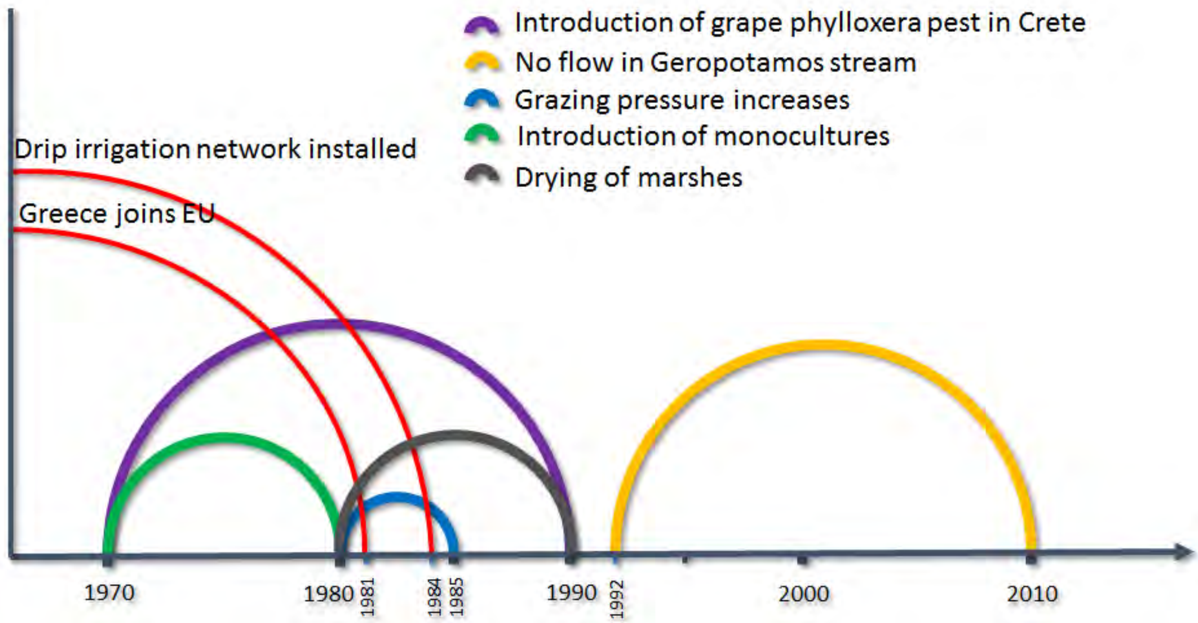



**Figure 77: Event timeline for the Messara basin since the 1970s.**

## 6.2 Main Causes of Land Degradation

### 6.2.1 Human induced Drivers

***Agricultural policy and excessive withdrawal of water***

In Crete, as in the rest of the country, high profitability of irrigated farming has led to over-exploitation of water resources. The amount of water allocated for irrigation is estimated to be 82% of the total consumption. In general, water consumption has increased by more than 4% per year (LEDDRA Project, 2013). Most of the total water consumption is used in agriculture for the irrigation of olive groves, vineyards and vegetables and the European Common Agricultural Policy (CAP) has significantly affected cropland areas and land use types. In Crete, many marginal areas under natural vegetation were cleared and olive groves have been planted. These areas become particularly vulnerable to erosion due to inadequate soil protection and reduction of infiltration rates which follows loss of organic matter content and soil structure decline. Widespread olive production in steep hilly areas in combination with the lack of water and grazing has resulted in desertification problems.

The main source of irrigation water in Messara is groundwater as there is little surface water flow outside the winter months (Vardavas et al., 1997). Groundwater is the key resource controlling the economic development of the region, and it comprises a component of the environment under siege as water demand is increasing with time. The increased demand of water, either for domestic or agricultural use, cannot always be met, despite adequate precipitation. Water imbalance is often experienced, due to temporal and spatial variations of precipitation, increased water demand during summer months and the difficulty of transporting water due to the mountainous areas. A characteristic example of groundwater overexploitation is the western part of Messara Valley (Croke et al., 2000; Vardavas et al., 1997). Lately, there have been growing concerns over the possible depletion or deterioration of the groundwater quality in the basin due to intensive pumping beyond the safe yield of the basin (Tsanis and Apostolaki, 2008).

In 1970, two irrigation systems were constructed in the area as prototypes for a future extensive network (Croke et al., 2000). At the time, the average groundwater level fluctuation over the hydrological year was about 3 m, which for a mean porosity of 0.05 for the clayey phreatic aquifer of the Valley gives an average recharge of 150 mm per year. Measurements have shown that the groundwater level at that time was about 5 m below surface and the maximum rate of withdrawal was 5 $Mm^3$ per year with discharge rates as high as 300 $m^3/h$. Then, the average surface discharge out of the Valley was 20 $Mm^3$ per year which corresponds to a loss as runoff about 50 mm per year (Tsanis and Apostolaki, 2008).

In 1984 an extensive network of groundwater pumping stations was established in Messara Valley, causing an increase in the rate of groundwater withdrawal and a dramatic drop in the groundwater level of about 20 m (Vardavas et al., 1997). Since the groundwater irrigation network was installed, the groundwater level has on average decreased by about 2 m per year as what used to be non-irrigated cultivation of vines and olive trees was transformed to drip-irrigated cultivation. The end effect is that about 660 mm of water per year, or about an average 2 mm per day, is lost from the Valley (Vardavas et al., 1997). Although the amount of water required for irrigation of olive plantations is relatively low compared to arable crops, there has been a dramatic over-exploitation of aquifers accompanied by water quality deterioration (Briassoulis, 2003;

Juntti and Wilson, 2005; Wilson and Juntti, 2005). In addition, regional development, infrastructure, spatial planning policies and the implementation of Integrated Mediterranean Programmes constitute the factors that have considerably affected the exploitation of natural resources (Kosmas et al., 2013). Finally, the sequential occurrence of dry years in the 1990s has led to more intensive pumping to meet the irrigation demands. As a result, in 2000 the groundwater level was 45 m below the surface. During the last three years, the runoff of the Geropotamos River is close to zero due to the percolation rate increase.

***Overgrazing***

Free-range livestock can, over time, degrade rangelands due to overgrazing. The rate of degradation depends on the density of the livestock population and the restoration rate of the natural flora. The relationship of those rates can be used as a tipping point index (Dimitrakopoulos et al., 2004). The direct effects of the introduction of domestic grazers on native faunas since prehistoric times are well described for the Mediterranean islands, where original faunas have been affected by species extinction and introductions promoted by humans. The Asteroussia and Psiloriti mountains of Crete represent characteristic cases of degradation caused by intensive grazing and fires set by shepherds. Soil erosion is apparent in many cases, and areas that appear irreversibly degraded (desertified) are often found (Hill et al., 1998). The grazing areas of the Psiloriti Mountains in central Crete extend into higher altitudes of sub-humid and humid Mediterranean climates (1,000-2,000 m). In areas often covered with matorral or mountainous phrygana, relict kermes oak forests (Quercus coccifera) are still found. Moreover, in this region grazing pressure has significantly increased (Hill et al., 1998). Statistical figures for some of the mountainous communities show an increase of the total number of sheep and goats by more than 200% between 1980 and 1990. Nevertheless, it has been observed that flora biodiversity can be fully restored by applying rational grazing on degraded areas when fertilization and fence application for at least a month take place. The implementation of such a program requires the removal of animals for a period of 2-3 years, after which the site can be grazed at carrying capacity.

### 6.2.2 Natural Drivers

Long-period drought assessment represented by 48-month SPI was carried out in order to provide an overview of prolonged drought occurrence during the period 1960-2002 (Figure 78). It is obvious that no prolonged drought events have taken place throughout the available record and the area is mostly under normal conditions. Nevertheless, especially extreme drought conditions took place in the years 1992–93 (Figure 78). Drought phenomena under mild conditions were also observed during the period 2000–02. The sensitivity of drought to the precipitation variability rather than the long term average is depicted in the SPI results. Regarding the Aridity Index, the area displays stability with a slight decreasing trend (Figure 79). This long term trend might have been significant but was overturned by the relatively large precipitation amount received in 2002 (905 mm). The area generally belongs to the semi-arid bracket with only four years crossing over to a more arid character. Nevertheless, this tendency to arid climate is possibly occurring at a higher frequency after the 1980s.

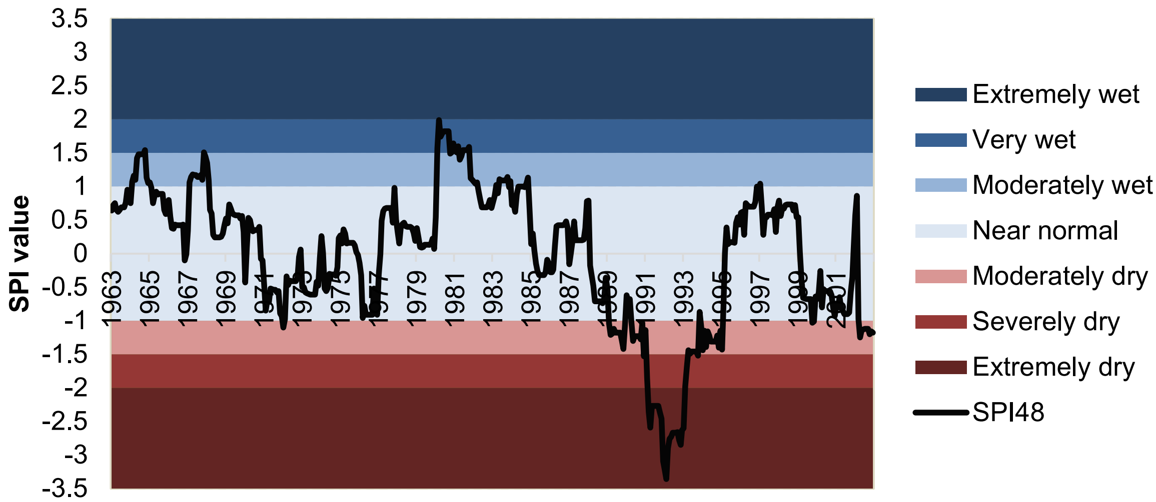



**Figure 78: SPI 48 estimated for the period 1963-2002 for the area of Pompia.**

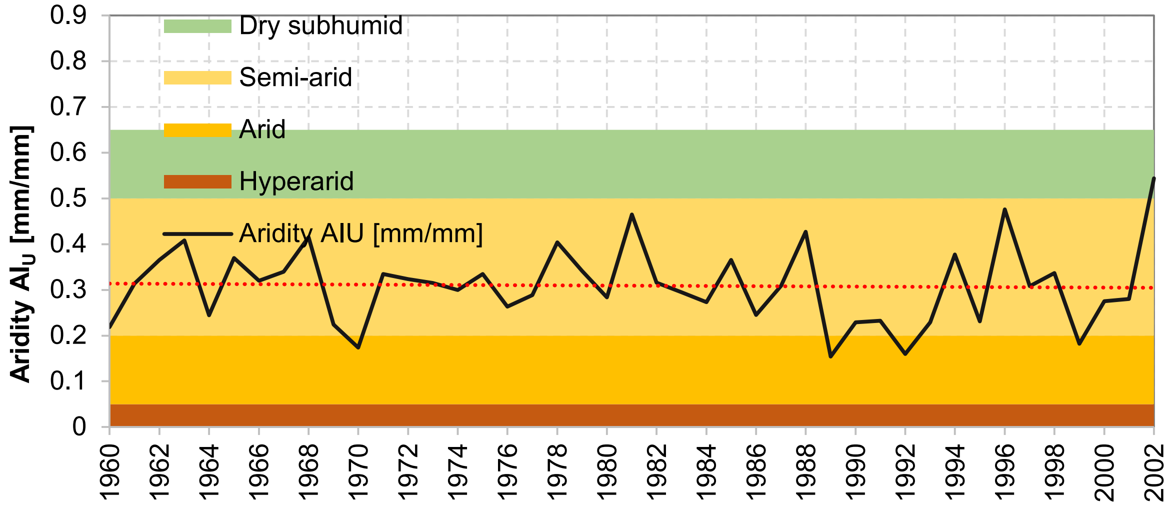



**Figure 79: Aridity estimated for the Pompia Area.**

### 6.2.3 Indirect causes

***Socioeconomic drivers***

Greece joined the EEC (European Economic Community) in 1981 and Greek agriculture became subject to the Common Agricultural Policy (CAP). Up until 1992, the aim of the CAP was to increase production, and to provide cheap rural products accompanied by reasonable rural incomes (LEDDRA Project, 2013). The consequences of the CAP in Greece were the intensification of agricultural production, extensive mechanisation of crop production, creation of monocultures, such as cotton and olive trees, large surpluses of some products, the disappearance of some unique Greek plant varieties which were replaced by hybrids, and the loss of the rural balance with its self-sufficiency in agricultural products (Kosmas et al., 2013). Greek farmers have re-orientated crop production towards the globalised market and Greek agriculture is no longer based solely on the needs of the country or the European Union. This has resulted in the orientation of

Greek agriculture to three main crops: olives, cotton and tobacco. As a result, the country has simultaneously lost its self-sufficiency in products such as cereals, fruits, and vegetables. Crete has not been an exception to this.

Rural migration has also had a significant impact on cropland and land management practices. Large scale migration from rural to urban areas took place in Greece after the 1950s and since then rural population has continued to decrease (Figure 80). As a result, land was either abandoned or rented. These conditions facilitated the over-exploitation of rural land from the few remaining farmers who often adopted harsh methods, such as uncontrolled burning of shrubs, otherwise condemned by neighboring users (Kosmas et al., 2000). At the same time, the total population of Crete has increased in the last four decades. The rate of increase was especially high in the area of Heraklion, putting significant pressure on land for transformation from agriculture to residential or industrial uses. Apart from urbanization, mass tourism has also put a pressure on the Cretan landscape in the last few decades. The total number of tourists in Crete exceeds 2 million per year and this number may double by 2025 (Chartzoulakis et al., 2001). As a result and a means to improve their financial profile, in less productive areas, particularly along the coast, farmers have sold their land to developers for the construction of tourist infrastructure.

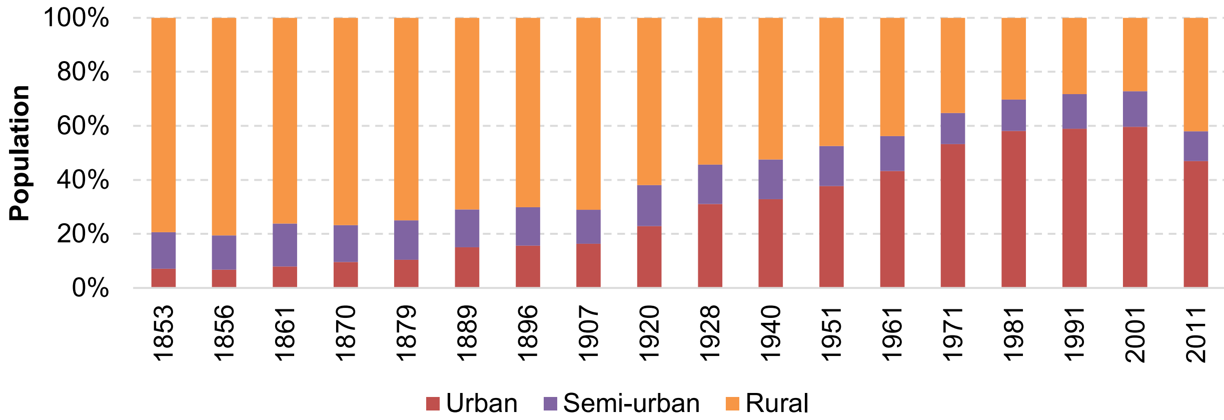



**Figure 80: Changes in urban and rural population between 1985 and 2010 in Greece. Based on data from Greek National Statistical Service.**

The CAP, through its structural policies, supported an adequate income to farmers, contributing to the development of regional economies and reform of landscapes, particularly in less favoured areas. In addition, subsidies allocated under the CAP accelerated the intensification and specialization process in agriculture. Subsidies, allocated based on the area cultivated encouraged farmers to keep highly degraded land under cultivation, or to expand cultivation into marginal areas, even with low crop yields, thus accelerating erosion and land degradation (Briassoulis, 2003; Louloudis et al., 2000). On the other hand, the lack of coordination between organizations (development agencies) and state services responsible for land management as well as knowledge gaps, have been liable for the lack of Cretan landscape policy application (Stobbelaar et al., 2000). Organized efforts from the EU strive to bridge these shortcomings in management, infrastructure and knowhow but there is still a long way ahead.

# 7 Randi Forest Study Site (CY)

Responsible partner: CUT (12)

## 7.1 Definition of the Randi Forest Study Site

### 7.1.1 General information

Cyprus is the third largest island in the Mediterranean, and is located in the South East Mediterranean, in the Levantine Basin, with an area of 9,250 km$^2$ (Hadjiparaskevas, 2001). The island of Cyprus is dominated by two mountain ranges: Troodos, which is located at the central and western part and Pentadaktylos at the north part (Kyrenia range). The geological history is characterized by marine sedimentation in a sea that became gradually shallow. The climate is intense Mediterranean, with wet variable winters from November to March, and long hot, dry summers from May to September, separated by short spring and autumn seasons of rapidly changing weather. The average annual rainfall is approximately 480 mm. The Pissouri area is located at the south zone of Cyprus, in the south east part of Paphos district area and consists of the Randi Forest (located in Pissouri basin), being characterized as drylands (Figure 81). Vegetation consists of plants from different habitats such as pine forests, phrygana, maquis, all growing around the rocky hill faces. In the Pissouri area, lack of rainfall leads to shallow soils and water erosion, while soils are further damaged by livestock grazing, thus impeding plant growth.

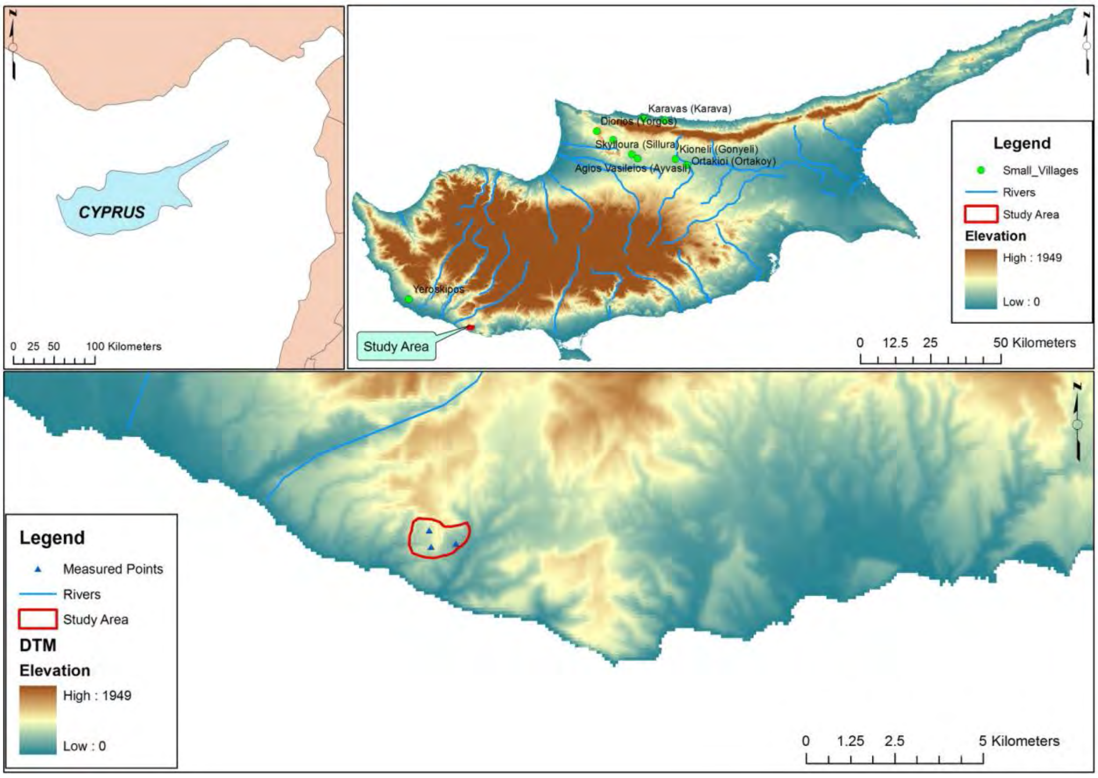



**Figure 81: Study area - Randi Forest.**

### 7.1.2 Topography

The topography of Cyprus is affected by the geology and dominated by the Troodos Mountains in the south and the Kyrenia Mountains along the northern coast and Mesaoria plain. The study area is the Randi Forest, which is approximately 14 $km^2$. However, the focus of the three Study Sites are located at coordinates 34°40.286N, 32°39.292E, 34°40.237N, 32°38.830E and 34°40.487'N, 32°38.797' E over an area of approximately 4 $km^2$ at an inclination of 20-25%. The topography ranges from 0 to 140 m above sea level (Figure 82). The sites were selected since in each location the three grazing conditions examined in the project were present.


**Figure 82: Topography of the study area.**

### 7.1.3 Geology and Soils

The dominating soils in the area are calcaric regosols, with a deep brown color. The soil contains clay round 25%, and has a silt content of 40%. In the valley and on hills there is a slight inclination of 20%. Deeper soils are presented (colluviums), with clay content of 30-40%, and silt content of 50%. Many parts of the area are characterized by severe topsoil erosion losses. Thus, the root system is limited by the underlying strata. Furthermore, the high $CaCO_3$ content and the clay soils reduce the infiltration rates and thus increase water erosion.

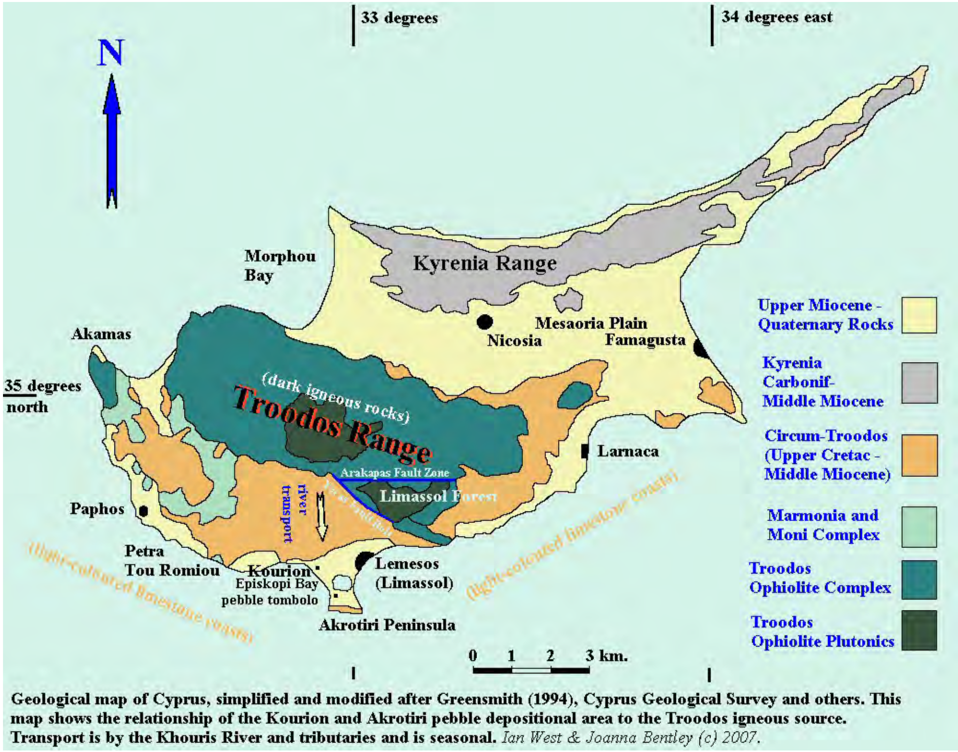



**Figure 83: Geological map of Cyprus.**

Soil studies and soil classification began in Cyprus in 1957 and consisted of the physical and chemical data of soil properties (Hadjiparaskevas, 2001). The majority of soils of Cyprus display near neutral to alkaline pH (>8) values when slurred with water, reflecting the influence of carbonates, as well as colluviums – alluvium areas and alkaline earth oxides and hydroxides derived from dominate formations. This is significantly more alkaline than the average for the rest of Europe (ph 5.5-5.8). Figure 84 provides an example of the soil formations in the area.

**Figure 84: Soil example from Study Site.**

### 7.1.4 Land Use

The sites consist of hilly terrain with light shrubbery. Land use maps indicate that the Study Site is an open area with shrubs and sparse carob and olive trees (Figure 85). Areas south of the forest consisted of vineyards, which have dried up due to lack of water. As the land is not suitable for agriculture, it is used for livestock grazing, in particular goats and sheep. Besides recent event, the major land use change occurred in the 30s, when Randi Forest was still an actual forest rather than its current shurbland state. "When interviewing people in the village, two old men aged 87 and 85 years old said that in the 1930s the British governor gave permission to the local people in the area to cut the trees and use them as firewood".

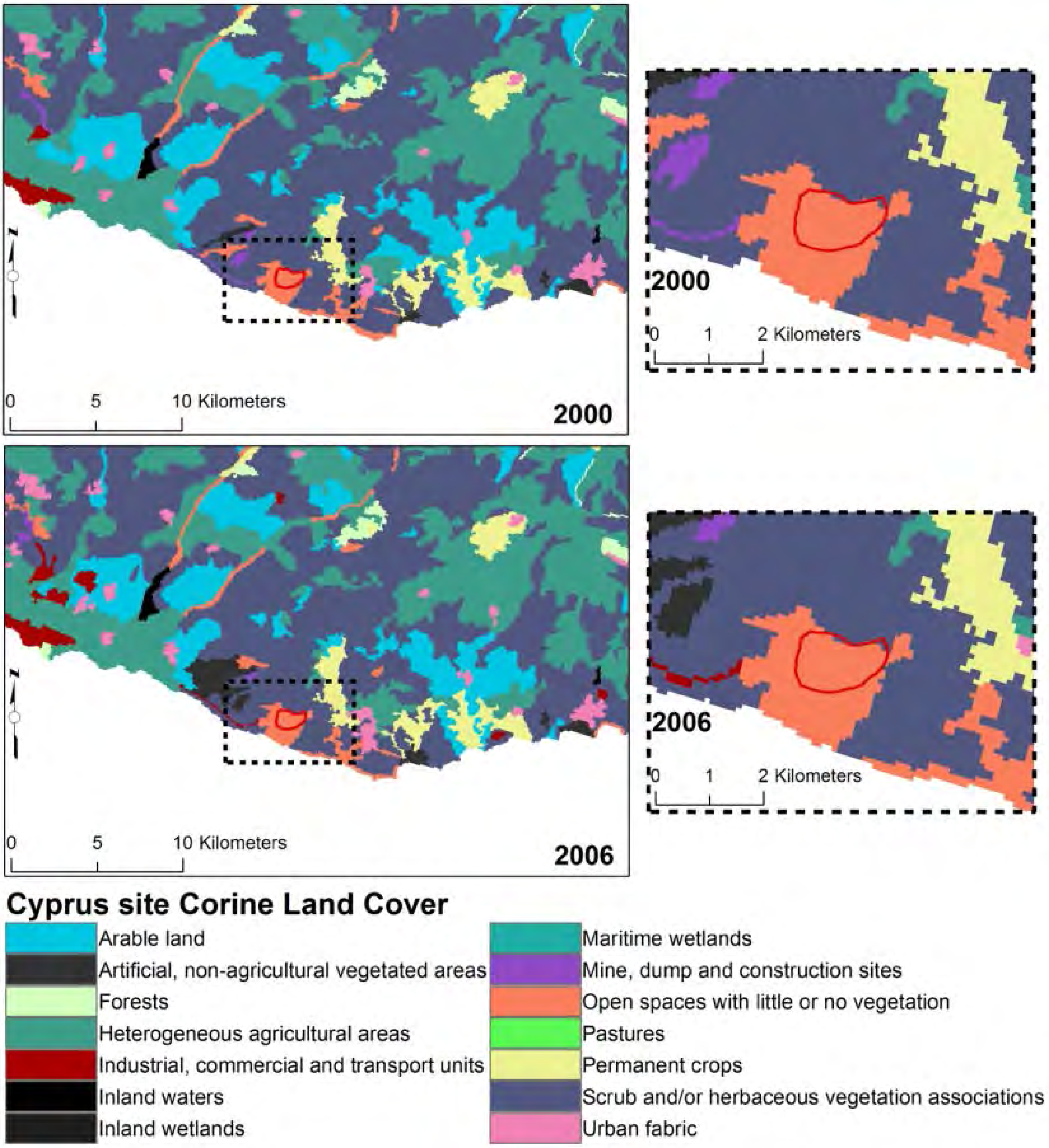



**Figure 85: Corine land cover map for the study area.**

### 7.1.5 Climate

The climate in Cyprus is intense Mediterranean, with wet, variable winters from November to March, and hot, dry summers from May to September, separated by short spring and autumn seasons of rapidly changing weather. According to the Ministry of Agriculture, Natural Resources and Environment (2002), the average annual rainfall in the area was 410 mm, from 1990 to 2000, and 440 mm from 1970 to 2000, which is below the 480 mm average over the whole island (Figure 86). However, annual rainfall data from the Asprokremmos region near the Randi Forest indicates an average rainfall of 490 mm. Figure 86 also shows that annual rainfall has decreased by almost 50%, from about 600 mm to about 330 mm, during the period 1960-2002.

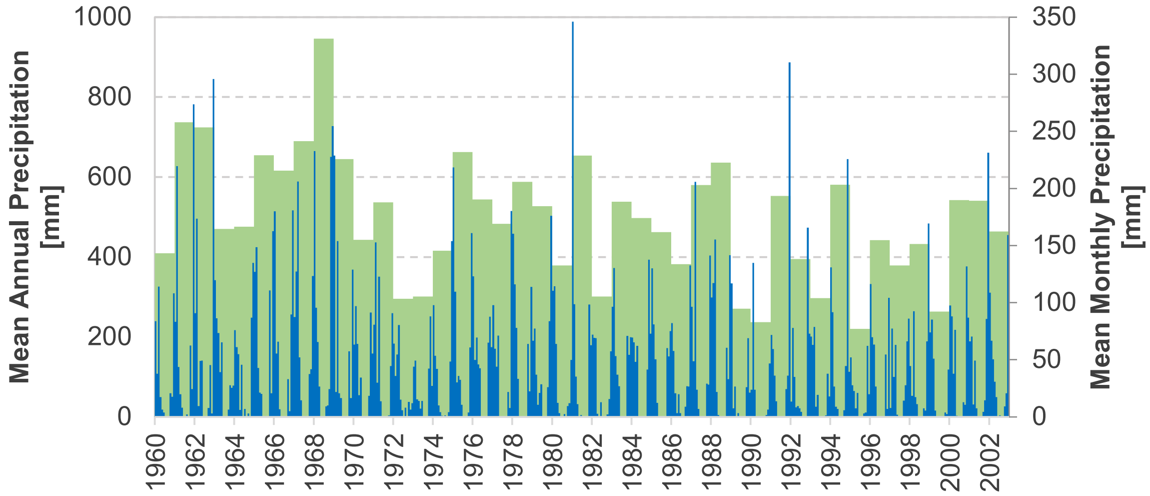



**Figure 86: Mean monthly (blue) and mean annual (green) precipitation measured at Asprokremos and infilled from the E-OBS dataset.**

The average annual temperature in the area is 33°C during summer and 15°C during winter-time. Figure 87 shows the monthly temperature fluctuation in the area, which has a relatively stable behavior for the length of the historical record and an annual average of 19.5 °C. In the study area, the average monthly evapotranspiration is 180 mm, with the potential evapotranspiration being 250 mm monthly. The potential evaporation in the area was estimated at 1,700 mm.

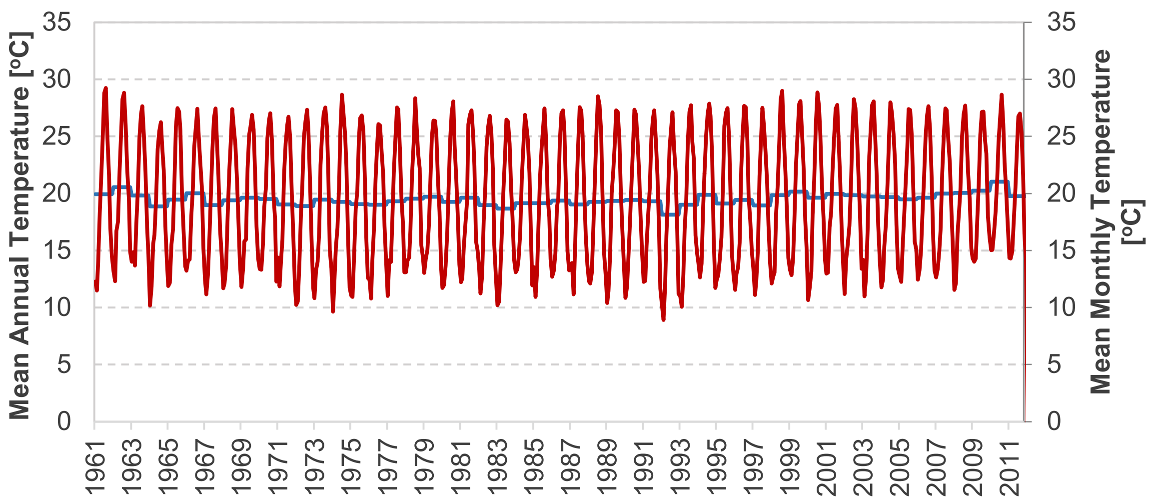



**Figure 87: Mean monthly temperature at Pissouri derived from the E-OBS dataset and corrected for bias.**

### 7.1.6 Hydrogeology

The period of zero precipitation in the area lasts for four months, from July until October. There is no information available regarding the groundwater level and the flow/runoff in the area. There is also no available information regarding the type and amount of irrigation water. The subject area just outside the Pissouri West is located over a Gypsum Aquifer (Water Development Division, 2002) as indicated in Figure 88. In the last few years, the aquifer has gained more importance because of the reduction in the diverted quantities of surface water. The aquifer is outcropping in several places. The recharge depends on rainfall and at a lesser degree on return flow from irrigation. The aquifer has yet to be studied in depth. The groundwater in this aquifer is supposed to always be saturated in sulfate ions ($SO_4^{--}$) the concentration of which ranges between 1400 and 1,500 mg/l which is beyond EU limits for drinking water (250 mg/l) but within the limits for irrigation (250 to 3,000 mg/l).

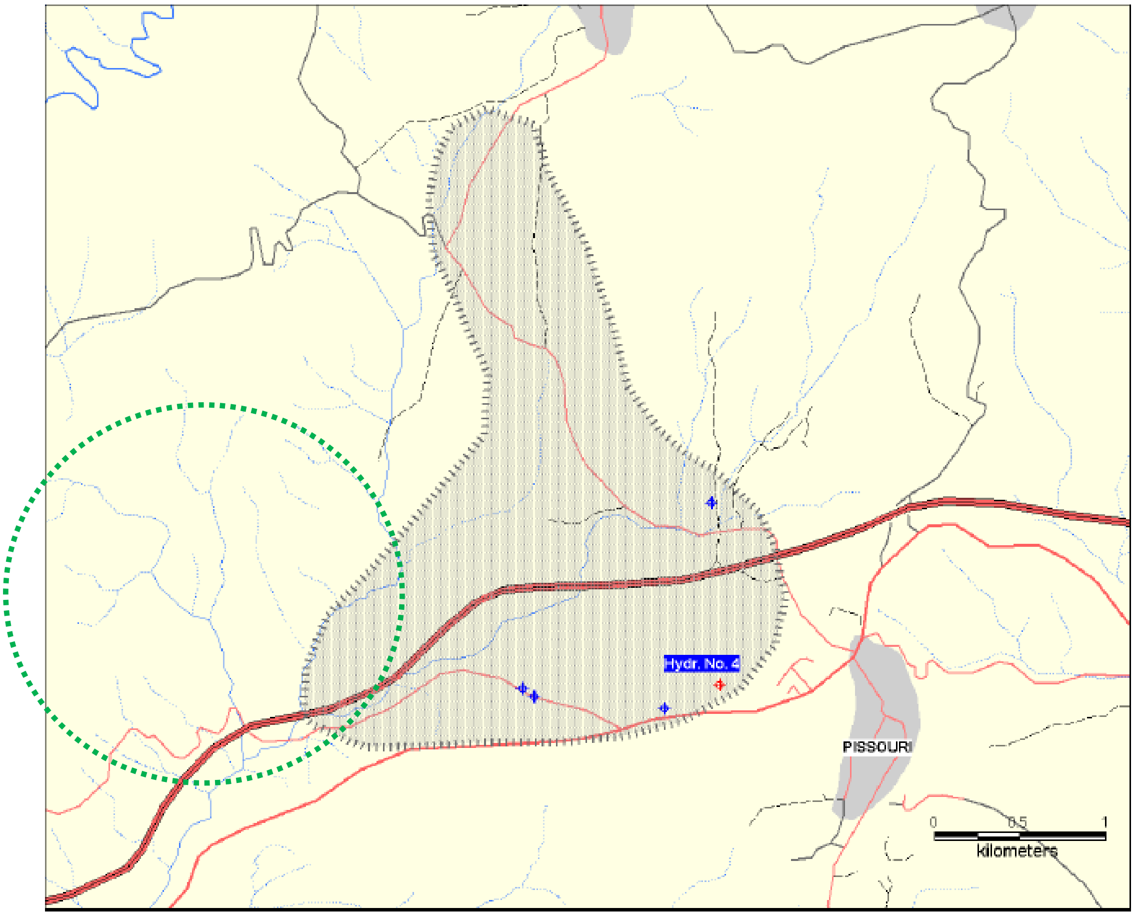



**Figure 88: Pissouri West Gypsum Aquifer. The Study Site is indicated in green.**

### 7.1.7 Main Ecosystems

Cyprus is a Mediterranean island, biogeographically isolated from the three regional continents and therefore the plant and animal species have evolved into endemic species (Hadjikyriakou and Hadjisterkotis, 2002). During the Neolithic and Chalcolithic eras, several species of large mammals (Hippopotami and Elephants) and alien plant species were introduced to the island (Davis, 1984, Hadjisterkotis et al., 2000). Cyprus is considered as a biodiversity “hotspot” area as it is the only center of bird’s endemism in Europe and the Middle East (Médail and Quézel, 1999).

***Flora***

The Cyprus flora includes in total 1,910 taxa (species, subspecies, varieties, forms and hybrids) as native or naturalized, among which 143 taxa are endemic. The percentage of endemics can reach over 20% within the Troodos mountains, where large numbers of endemic plants such as the cedar (*Cedrus brevifolia*) and the golden oak (*Quercus alnifolia*) grow. The varied microclimate and geology is the main reason for the high number of endemic species.

In the area of interest, the natural landscape is dominated by scrublands, the typical Mediterranean maquis, Garigue and Phrygana. This landscape has been formed by man-made activities such as forest destruction with subsequent periodic burning and overgrazing, followed by soil erosion. Where soil is not significantly eroded and ecological factors are favorable (slope, aspect, moisture), succession follows from phrygana to garigue and finaly to maquis. Most of the shrubs are sclerophyllous of varied heights such as *Calycotome villosa, Genista fasselata* and *Rhamnus oleoides* (Figure 89). Trees are scattered in the area and consist mainly of Olea europaea, Ceratonia siliqua and Pinus species. The Bromus and Malva species are found among the shrubs and tree grasslands. For the purpose of the CASCADE project, plants in the area of interest were identified using the natural key system which is based on morphological characteristics such as structures of stems, roots and leaves, embryology and flowers. Plant parts were collected and photographed from an area of 50 ha.

**Calycotome villosa**

**Ceratonia siliqua**

**Rhamnus oleoides**

**Pistacia lentiscus**

**Figure 89: Typical vegetation types of Pissouri basin.**

In total, 57 species were identified within the area of interest. Various types of shrub communities dominate in the thermo-Mediterranean semi-arid zones. The area of interest is a typical coastal zone with dry grasslands, shrubs and forest openings. Trees, shrubs and grass were observed among the species, where the most dominant ones in the area were *Olea europaea*, *Calycotome villosa, Cistus parviflorus, Genista fasselata, Sinapis alba, Malva sylvestris* and wild poaceae species. Eighteen plant families were observed (Anacardiaceae, Apiaceae, Asteraceae, Cistaceae, Compositae, Ericaceae, Fabaceae, Lamiaceae, Malvaceae, Oleaceae, Papillionacea, Pinaceae, Poaceae, *Ranumculaceae*, Rosaceae, Rubiaceae, Urticaceae and Zygophyllaceae). The binomial nomenclature of the plants is shown in Table 7.

**Table 7: Plants identified in Pissouri area**

| A/A | Plant Species | A/A | Plant Species |
|---|---|---|---|
| 1 | *Allium roseum* | 30 | *Nomea mucronats* |
| 2 | *Anthemis parvifolia* | 31 | *Notoposis sp* |
| 3 | *Anthemis plutonia* | 32 | *Olea europaea* |
| 4 | *Arbutus andrachne* | 33 | *Onopordum cyprium* |
| 5 | *Asfodelos sp* | 34 | *Phagnalon grecum* |
| 6 | *Asperula cypria* | 35 | *Phagnalon rupestre* |
| 7 | *Avena fatua* | 36 | *Phalaris minor* |
| 8 | *Avena sterilis* | 37 | *Pinus brutia* |
| 9 | *Bromus arvensis* | 38 | *Pistacia lentiscus* |
| 10 | *Bromus sterilis* | 39 | *Pistacia terebinthus* |
| 11 | *Bromus sterilis* | 40 | *Plantago lanceolata* |
| 12 | *Bromus tectorum* | 41 | *Quercus alnifolia* |
| 13 | *Calycotome villosa* | 42 | *Ranumculus sp* |
| 14 | *Centaurea cyprium* | 43 | *Rhamnus oleoides* |
| 15 | *Centaurea pallescens* | 44 | *Sarcopoterium spinosum* |
| 16 | *Ceratonia siliqua* | 45 | *Scila morissi* |
| 17 | *Chrysanthemum coronarium* | 46 | *Scorpioros muricatus* |
| 18 | *Cirsium arvense* | 47 | *Senecio glaucus* |
| 19 | *Cistus parviflorus* | 48 | *Setaria glauca* |
| 20 | *Cota amblyolepis* | 49 | *Sinapis alba* |
| 21 | *Daucus carota* | 50 | *Tanacetum balsamita* |

| | | | |
|---|---|---|---|
| 22 | *Erptium sp* | 51 | *Tanacetum cinerarifolium* |
| 23 | *Fagonia cretica* | 52 | *Taraxacum aphrogenes* |
| 24 | *Genista fasselata* | 53 | *Taraxacum officinalis* |
| 25 | *Hordeum murinum* | 54 | *Thymus capitatus* |
| 26 | *Inula viscosa* | 55 | *Tribulus terrestris* |
| 27 | *Lolium rigidum* | 56 | *Trifolium sp* |
| 28 | *Mafricaria chamomile* | 57 | *Urtica urens* |
| 29 | *Malva sylvestris* | | |

A synoptic view of vegetation health and the associated function of ecosystems can be derived from analysis of archival and on-going sequences of NDVI. Figure 90 depicts NDVI change through time using datasets from Pinzon et al. (2005) and Tucker et al. (2005). New estimations from LandSat imagery (black circles) at the exact locations of the Study Site were used to correct the global dataset for bias. NDVI in the study area shows no significant trend since the 1980s. Nevertheless, NDVI values are significantly low.

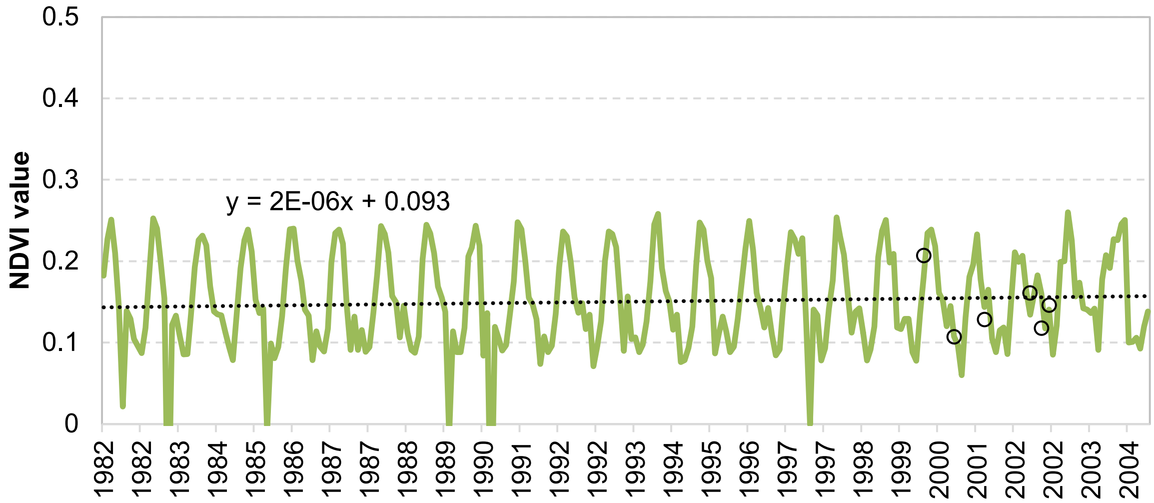



**Figure 90: Historical evolution of NDVI through time (green) corrected for bias using value from LandSat imagery (black circles).**

***Fauna***

The island of Cyprus dipslays diverse fauna due to the fact that the island is at the crossway of three continents and also due to the wide range of habitats present on the island. The fauna of Cyprus includes endemic species of mammals, snakes, birds, etc. The island is considered to be an important endemic region for birds from alover the world, while it constitutes one from the 8 most important migratory routes for the birds in Europe. In Cyprus, 9 mammal species are included in the Annex of II Directive 92/43, and in particular one as priority. Two mammals are included in the Annex I of the Habitat Directive i.e. the Cyprus muflon (*Ovis orientalis ophion*) and fruitbat *Rousettus* *aegyptiacus*. More than 385 species of birds have been recorded in Cyprus, 53 as permanent residents and the rest as migratory. In Cyprus, 24 species of reptiles and 3 species of amphibians are documented. Four endemic subspecies of lizards and two endemic species of snake are reported, as well as two endemic subspecies. The Cypriot snake *Coluber cypriensis* and the grass snake *Natrix natrix cypriaca* are both endemic species of reptiles in Cyprus. The Cyprus snake *Coluber cypriensis* was added in Annexes II and IV of Directive 92/43/EEC, as priority species. It has been characterized as endangered (EN) by IUCN as the threats for this species increase mainly due to human activities and fires.

In the area of interest, fauna consists of birds, mammals, insects and reptiles. From the category of birds, the species *Alectoris chukar, Coturnix coturnix*, *Tyto alba, Streptopelia turtur and Pica pica,* where identified. From the category of insects, Lepidoptera, Hemiptera, Orthoptera and Coleoptera where identified. Mammals like *Lepus capensis*, *Hemiechinus aurithus and Vulpes vulpes* where observed during a night visit. Within the category of mammals, goats and sheep are included as domesticated and not wild animals.

***Selected Vegetation – soil system***

In the area of interest, the main vegetation is consisted of Phrygana, mostly *Calycotome villosa, Genista fasselata* and *Rhamnus oleoides*. The selected plant for monitoring is *R. oleoides* which is the most common and at the same time, uniform in terms of shape and size.

### 7.1.8 Timeline of events

Figure 91 shows a brief event timeline of the most important changes and milestones that occurred in the natural and social environment of Cyprus and the Randi Forest area.

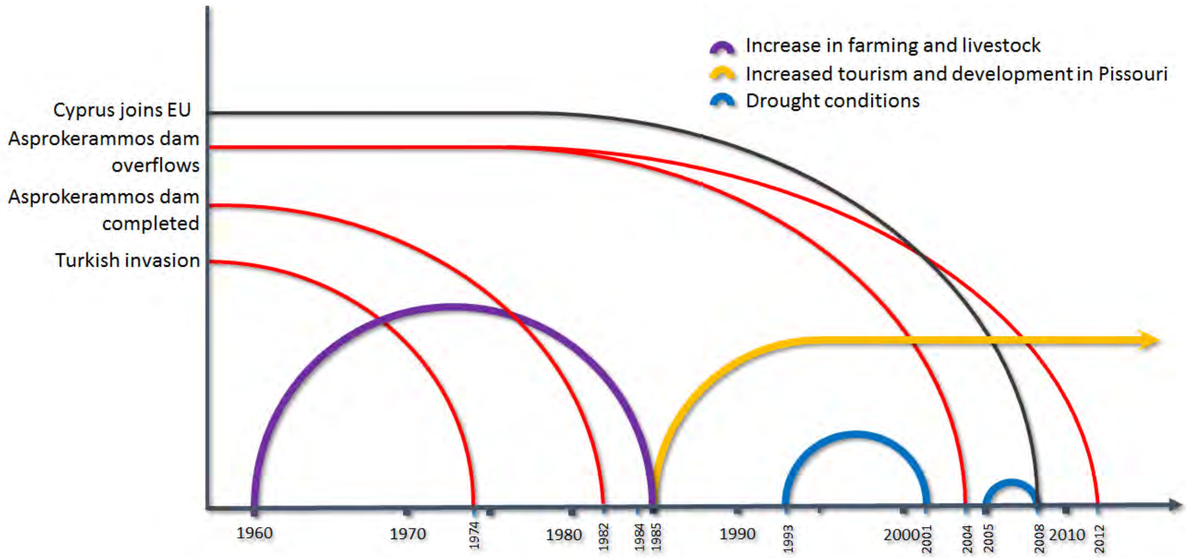



**Figure 91: Event timeline for Randi Forest since the 1970s.**

### 7.1.9 Socioeconomic status

Pissouri has experienced continuous population growth. In 1881 the inhabitants were 482, increasing to 956 in 1931, in 1960 amounted to 1,072 and by 1973, the population was 1,030 inhabitants. The current permanent population in the Pissouri area is approximately 1,400 people, about half of whom are Cypriots and half of whom are expatriates, primarily from the United Kingdom.

Pissouri was a very traditional agricultural village, producing grapes, wine, potatoes and citrus fruits. There are also many olive, carob and almond trees in the area. Livestock grazing, especially sheep and goats, was also common. However, in recent years, farmers had to eradicate big part of their vineyards, as they became profitless and, instead, focused on housing development and the tourist industry in the south part of the village. This has led to a significant decline in the agricultural sector. The livestock sector was moved to the northwest area of Pissouri, which is where the Study Site is located.

## 7.2 Main Causes of Land Degradation

### 7.2.1 Human induced Drivers

Historically, the study area was predominately used for agriculture. However, in the last few decades, the southern Pissouri area was affected by expanded development and coastal urbanization. As a result, the agricultural land in the area was lost to building development. In the northern part of the Pissouri area, the agricultural land remained uncultivated. After 1995, the lack of rainfall resulted in the decline of flora in the area. As the area could no longer be used for agriculture, the area north of Pissouri, which is the Randi Forest, was used for livestock grazing. Moreover, as the Pissouri Cliffs, to the south of the Randi Forest, are considered a protected area the space available for livestock grazing was further minimized.

***Overgrazing***

As the land in the area is not suitable for agriculture, it is used for livestock, in particular goats and sheep. The government had allocated permits to licensed shepherds permitting grazing for approximately 600 goats and sheep. Nevertheless, the actual number of animals grazing in Randi Forest is more than 3,700. Unlicensed shepherds are said to own another 1,240 animals that graze in this area. As a result, an additional 4,000 animals are estimated to graze in Randi Forest. The amount of land allocated within the area for grazing is around 1,000 ha, which is approximately 70% of Randi Forest. As a result of overgrazing and the dry climate of the island, vegetation has significantly diminished in the area. Moreover, livestock presents a significant source of pollution for both soil and groundwater reservoirs, resulting from the large quantities of liquid and solid waste from the farming activity.

### 7.2.2 Natural Drivers

The arid climate in the area, coupled with soil erosion, prevent the proliferation of flora in the area. This is further affected by the overgrazing of the livestock population. Long-period drought assessment represented by 48-month SPI was carried out in order to provide an overview of prolonged drought occurrence during the period 1963-2012 (Figure 92). A prolonged drought event took place during 1993-2001, only interrupted by a brief period of normal conditions in 1995. Droughts of shorter duration and intensity also took place around 1975 and 2008.

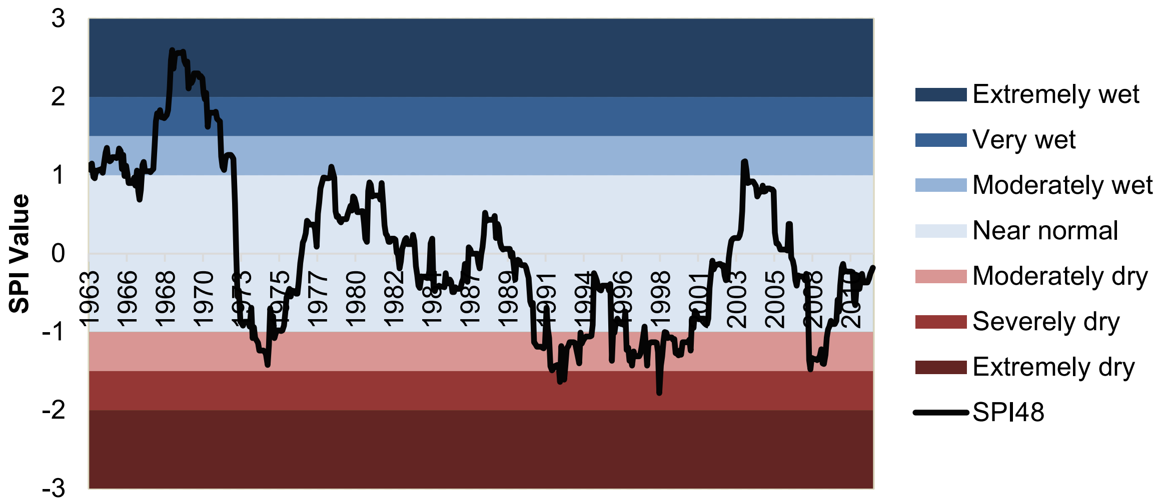



**Figure 92: SPI 48 estimated for the period 1963-2012 for the area of Randi Forest.**

What is interesting in the area is a possibly significant negative trend observed both in the SPI and aridity plots (Figure 92 and Figure 93). While on average conditions do not appear to be on the extreme side of dry or arid, the situation has taken a turn to more distressing figures during the recent decades.

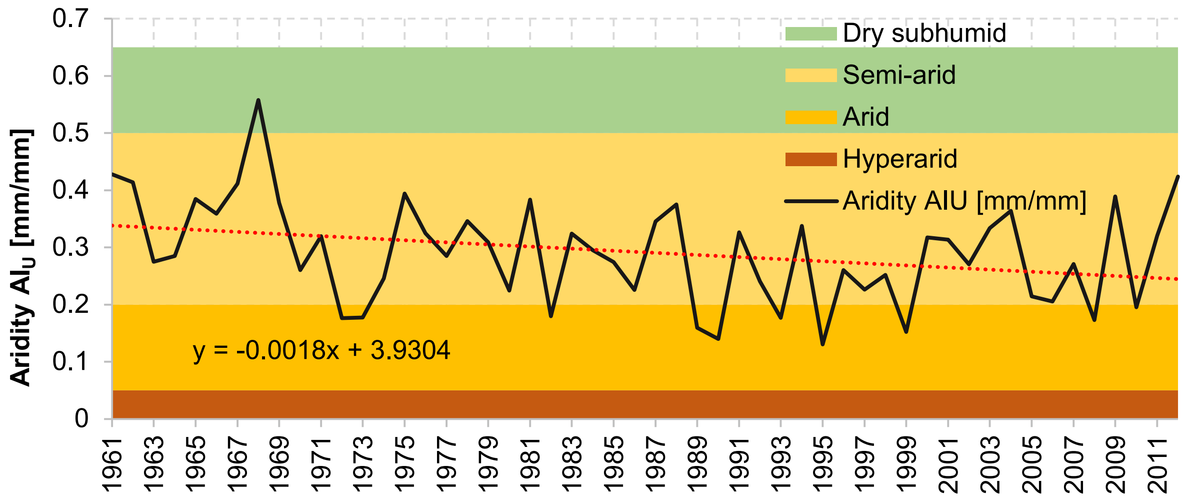



**Figure 93: Aridity Index estimated for Randi Forest.**

### 7.2.3 Indirect causes

***Socioeconomic drivers***

Sheep and goats play an important role in the economy of Cyprus in terms of meat and milk production (Hadjipavlou, 2012), as seen in Figure 94 and Figure 95. Although goats and sheep take up 18% of value animal production (including both meat and milk), they cover 90% of demand for goat and sheep products (both meat and milk) so that only 10% of relevant products is imported. Goat and sheep milk make up 22% of the total milk production in Cyprus, with the remaining 78% coming from cattle.

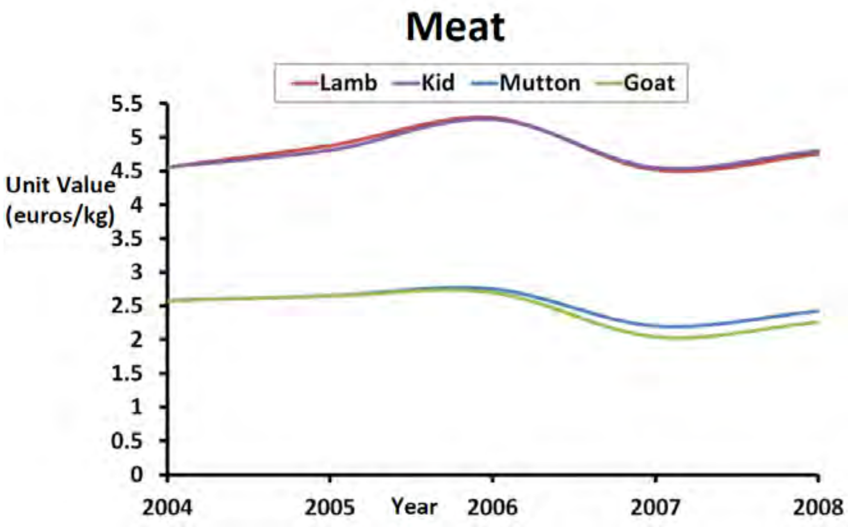



**Figure 94: Value of Sheep and Goat products.**

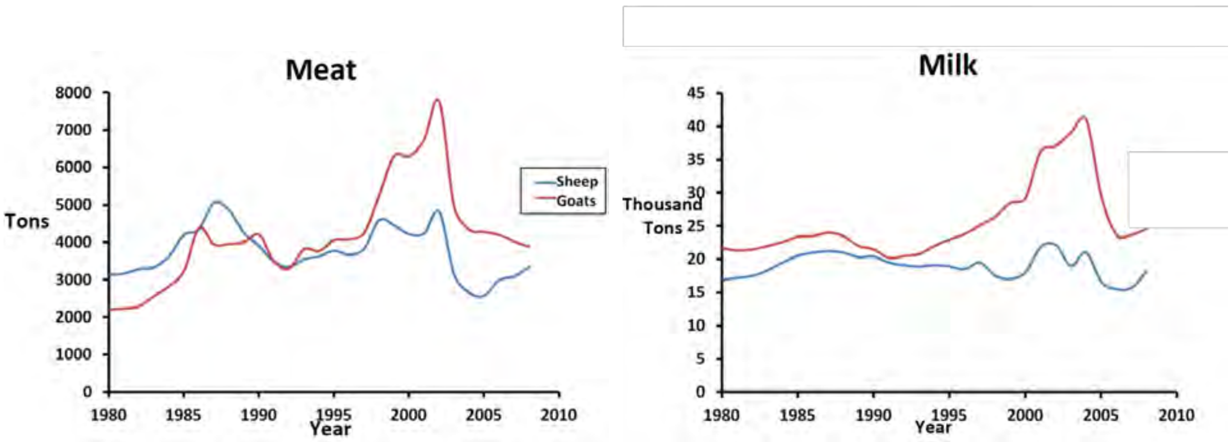



**Figure 95: Sheep and goat products - meat and milk.**

From 2000 to 2008, Cyprus faced a 34% decline in goat and sheep populations, due to the declining number of farming units, the aging farmer's population and climate variability (Hadjipavlou, 2012). The increase of protected areas in Cyprus has resulted in the relocation of the livestock around the Randi Forest area for grazing, increasing the amount of livestock in the area beyond what is permitted by the Government. As the Government does not strictly monitor the area, there is an over-abundance of goats and sheep for the area that resulted in the overgrazing that is evident in the study area.

# 8 Synthesis and Conclusions

The CASCADE Study Sites have a similar topography, mostly clustered around elevations of 400-700 m, with the exception of Castelsaraceno located at higher grounds and Randi forest which is closer to sea level. This distribution will possibly allow for an easier comparison between sites and also provide a view for marginal cases at later stages of CASCADE. There is also some uniformity in the geology and soils of the Study Sites, as in 4 of them (Albatera, Ayora, Messara and Randi Forest) soils are mostly shallow due to centuries of agricultural exploitation, subsequent abandonment and erosion. These shallow profiles also consist of calcaric material which does not promote vegetation growth. In all Study Sites the dominant land use is open spaces with scrubland and/or herbaceous vegetation associations, sometimes with various degrees of transitions between forest and shrubland. Forest cover is highest in the Study Sites Várzea and Ayora and agriculture is in some cases also present at the margin of the Sites. In all cases, the main ecosystem services are related to shrubs with some degree of natural or introduced forest vegetation that is primarily pine trees (Maritime, Aleppo, etc.). Ecosystem value includes provisioning, supporting, regulating and cultural services in a diverse blend that makes Mediterranean regions so unique. It is noteworthy that although Study Sites are part of the natural environment, their adjacent landscapes have been shaped up to a degree by human input, as is the case in most Mediterranean regions. This input, such as marginal agriculture, the introduction of grazers, and in many cases deforestation has often been negative but has also formed the unique ecological character of these regions.

Climatic conditions cover a wide range as well, with a long term minimum average annual precipitation being observed in Albatera (267 mm) and maximum average annual values at Várzea (1,170 mm) and Castelsaraceno (1,290 mm). For the latter, high precipitation values are obviously linked to the higher elevation. The rest of the Study Sites receive around 450 mm of precipitation. Respectively, the lowest average annual temperatures are observed in Várzea (13 $^{o}$C) and Castelsaraceno (9 $^{o}$C) with the rest of the sites ranging between 17-18 $^{o}$C. The only exception is Randi Forest with an extreme average annual temperature of 19.5 $^{o}$C. It is noteworthy that temperature appears to have some degree of upward trend in the past 40 years in all cases. This trend is less pronounced in the Eastern Mediterranean (Messara and Randi Forest) with a rise of 0.1 $^{o}$C per decade while in the rest of the sites temperature rises by 0.3 to 0.5 $^{o}$C per decade.

Among all Study Sites, Várzea and Castelsaraceno display the least signs of weather related aridity or humidity deficiency (Figure 96). In fact, their long term climatic conditions do not classify them as drylands. Nevertheless, they are both displaying clear trends to enter the dry-subhumid zone as the available 40-year records show a decrease in precipitation and a parallel increase in temperature. Both these sites are also seasonally dry and therefore suffer from drought-related problems. This factor, along with human induced drivers makes them susceptible to land degradation. The rest of the Study Sites are either semi-arid or arid with varying inter-annual behaviour that in some cases approached hyper-arid conditions. Taking into account the uniformly positive temperature trends that appear to agree with climate change scenarios, there is a high probability that these conditions will aggravate in the years to come.

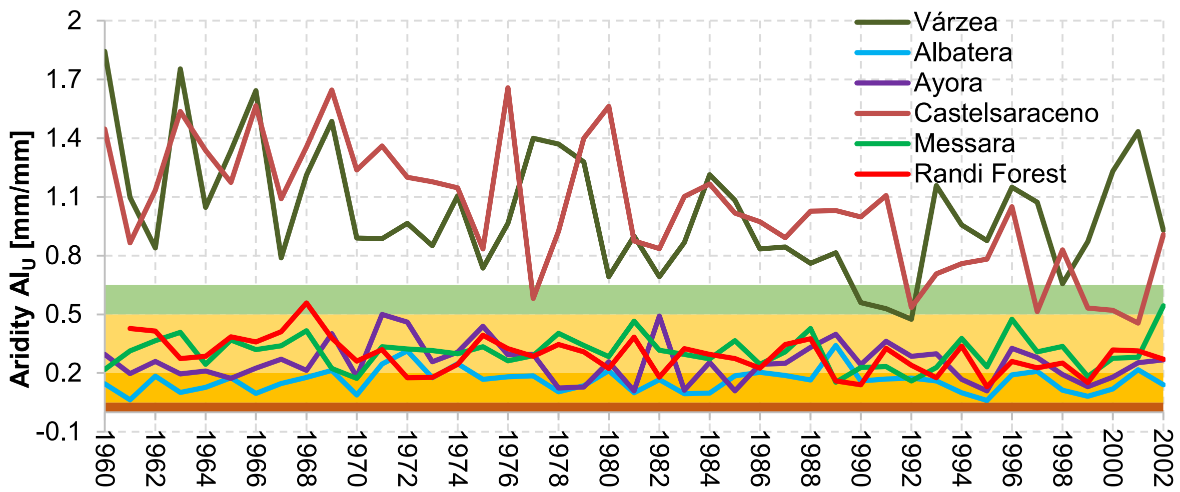



**Figure 96: Aridity Index for the CASCADE Study Sites.**

Following the methodology described earlier in this report, NDVI data and Landsat images were analyzed for the 6 Study Sites of CASCADE. Generally, there is a lack of Landsat datasets between 1990 and 2000 for these regions, which does not allow full analysis based on original imagery. Therefore most of the current assessment was carried out from lower resolution data, bias corrected from individual Landsat images. Seasonal results are presented in Figure 97 (for full time series see also chapters on individual Study Sites). By far the poorest vegetation state can be found in the Study Site of Randi Forest, followed by Albatera and Messara (Table 8). On the other hand, Castelsaraceno and Várzea seem to be at a better state on the long-term. Castelsaraceno also shows the highest NDVI fluctuation, possibly due to the effect of altitude, followed by Messara and Randi Forest. Specifically for each site, the area of Várzea in Portugal oscillates around a mean NDVI of 0.548, with an absolute maximum of 0.653 and an absolute minimum of 0.366. On average the highest vegetation activity can be observed in July and June and the lowest in December and January. In Albatera, the average NDVI is 0.184 and presents a seasonal high during the winter and spring months (December to April) with an absolute peak in March. The seasonal low is during the summer months (June to August) at an almost equal distribution. Much like Albatera, Ayora presents very small inter-annual fluctuations of the NDVI value, with summer months presenting the smallest chlorophyll activity and an average of 0.381. The two previous cases come in significant contrast with the case of Castelsaraceno. Here, the monthly fluctuation is well differentiated with increased summer NDVI values and lower activity during winter. The highest NDVI value is observer during June (record median around 0.65) but the same month also displays a high level of uncertainty which signifies the instability of the variable. The Messara Study Site also displays a well depicted difference between seasons. Nevertheless, instead of an increasing NDVI during summer months, like in Castelsaraceno and Várzea, the fluctuation of observations shows more similarities with the cases of Albatera and Ayora. February shows the highest values with an annual median of 0.48 while the long term average in the area is 0.35 (Table 8). In Randi Forest, summers can indeed be very harsh, sometimes reducing vegetation activity to zero from June to August. February and March are the most favorable months for vegetation, with October and November showing on average steadily lower values of NDVI. This Study Site has the absolute lowest average NDVI (0.158).

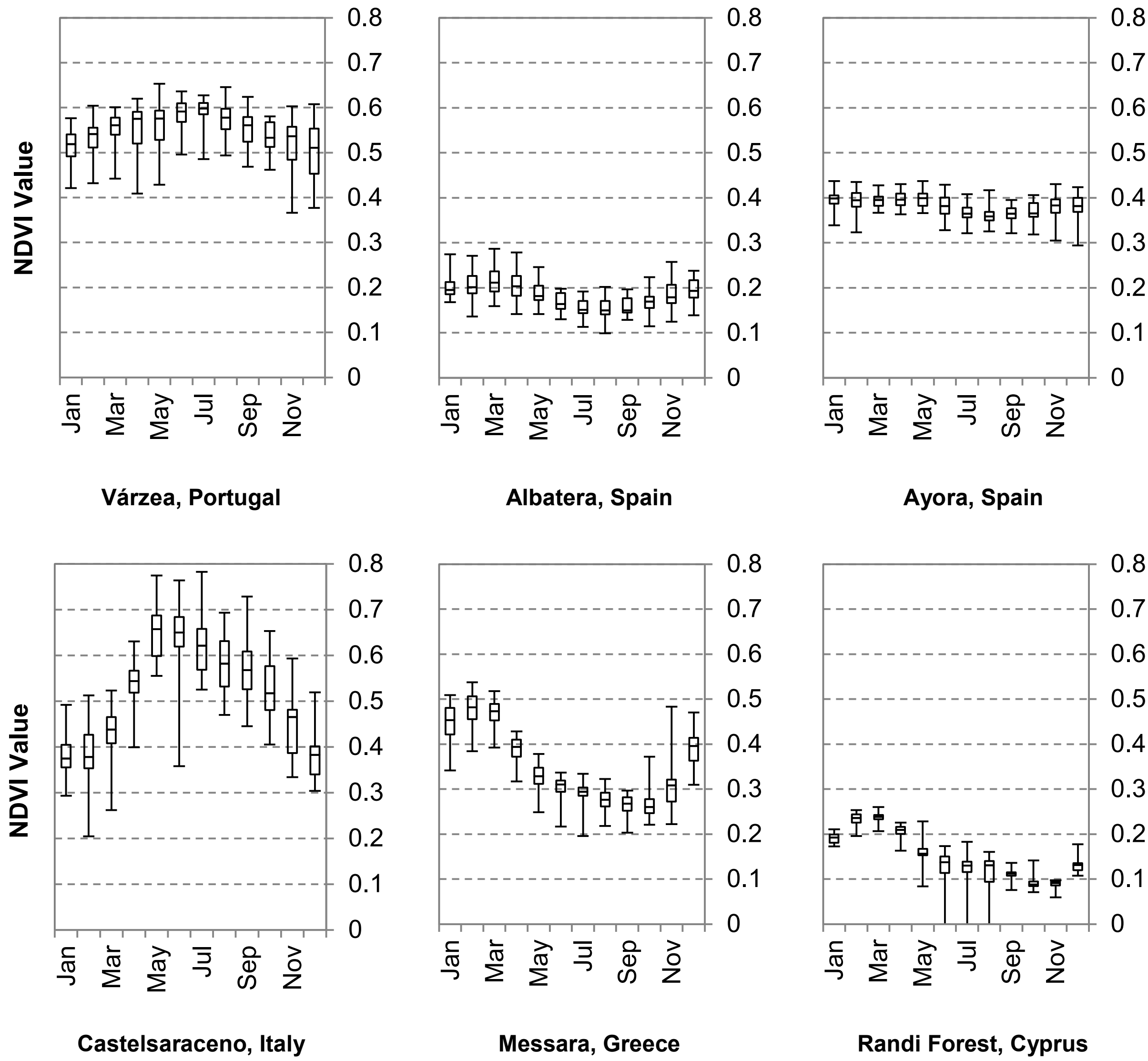



**Figure 97: Monthly NDVI values for the CASCADE Study Sites.**

**Table 8: NDVI statistics (mean and standard deviation) for the 6 Study Sites of CASCADE.**

| Site | Várzea | Albatera | Ayora | Castelsaraceno | Messara | Randi Forest |
|---|---|---|---|---|---|---|
| **Mean NDVI** | 0.548 | 0.184 | 0.381 | 0.514 | 0.350 | 0.158 |
| **Stdev NDVI** | 0.050 | 0.030 | 0.030 | 0.117 | 0.080 | 0.080 |

These results indicate that RS derived vegetation indices have a high potential for assessing vegetation activity, as a result of both climatic and human induced drivers. In one word, a continuously decreasing vegetation index along the years is a sign of desertification. Combined with land cover/land form/rainfall information and calibrated on the ground with biomass measurements, NDVI can provide significant indications, even quantitative, on the different types of vegetation degradation (or restoration) and on the recurrent drought factor related to it. A general conclusion from the analysis of chlorophyll reflectance from satellite imagery is that all sites show only minor trends in the NDVI index, with the exception of Albatera where a strong correlation seems to exist. While this fact infers that these systems are still not under any long term distortion leading to extensive degradation, the scales that have been considered up to this point are rather coarse. Historical developments as well as the current vegetation status indicate that when certain thresholds are being approached, significant changes in NDVI can occur. The seasonality of vegetation and possible annual or inter-annual changes can be further investigated using more advanced tools such as Fourier or wavelet transform. These tools may identify possible anomalies on shorter temporal scales or after selected events such as droughts or fires. CASCADE can remain open to the prospect of the use of RS data for selected Study Sites, in order to extract meaningful conclusions beyond the scope of the WP3 designed experiment.

The socioeconomic backgrounds of all Study Sites follow patterns similar to those met in the desertification paradigm (Reynolds et al., 2007). The decline in young population that abandons the rural ways in favor of a more modern urban lifestyle, better education and employment opportunities is an ever occurring feature. The remaining population is aging, often has considerable levels of analphabetism and thus limited resources for sustainable land, farm and animal management. Subsequent land abandonment patterns imply that the rural landscape presented, and may still present, fewer opportunities for work and livelihood, that fewer incentives have been given to balance the advantages of the urban lifestyle, or that these incentives and advantages have been poorly transmitted through dissemination channels, upbringing or formal education. Land abandonment has resulted in the deterioration of what is perceived as the desirable ecological status and ecosystem services. Nevertheless, the responsibility of local or national managing authorities to mitigate natural and human induced perturbations, such as fuel load buildup, overgrazing, land use mismanagement, etc. is also great. These conditions are often worsened by individual bad management decisions that may look profitable in the short term but have adverse long-term results for both the environment and livelihood of the community. For example, over-extraction of groundwater allows short term gains through irrigation, but can cause long-term damage to both the environment (e.g. drying up of wetlands) and the community (falling water levels, salinization problems). Droughts certainly increase various risks related to poor land management, such as fire hazard and groundwater depletion, thus accelerating the downward spiral of degradation and desertification.

In close relation to mismanagement, the impact of EU policy is more often seen as an adverse factor rather than an aid or a tool to improve product and production quality or the wellbeing of the ecosystem and the community. The crisis in traditional farming systems, accelerated by national and higher level agricultural policies, translated into the adoption of increasingly mechanized mass crop production and intensive farming practices which often prove inappropriate to local terrain. Rural areas have been hit by increasingly severe processes of degradation caused by intensive farming practices and changes brought in to crop production, phenomena which are closely linked to the social and economic changes which continue to impact rural areas. The progressive decline in traditional agricultural practices due to the absence of adequate research and development of traditional agricultural techniques could, however, see a turn-around in current European agricultural policy whose objectives are not solely based on maximizing production but also very much on environmental protection and qualification of local products and local territories (Quaranta, 2008). Although not specifically mentioning Mediterranean states, the new EU CAP addresses strategic objectives particularly relevant to the region. The resent reform features a more flexible and fairer distribution of financial support while respecting local priorities. Moreover, the financial crisis now faced by many southern states may eventually present a significant part of the urban population with opportunities to escape poverty and unemployment through a decentralization wave towards the often more hospitable Mediterranean rural lifestyle.

At first glance, the main causes of degradation for each Study Site are different, but they are always relevant to the accumulated impact of a driver: forest fires, marginal agriculture, grazing and wood-gathering activities, and long-term poor land management that is difficult to overturn. Less often, the causes are related to climate, which nevertheless serves as a catalyst. This accumulated impact may be associated with the concept of sudden ecosystem shifts beyond thresholds that preclude successful restoration of the desirable ecosystem properties and services. Sudden transitions have been shown to occur under continuous external stress, such as decreased water availability or increased grazing (Kéfi et al., 2007). Such changes have previously been documented in the transition of a green Sahara to its current desert state (Foley et al., 2003), but there is evidence similar changes can occur in the semi-arid Mediterranean as well (Kéfi et al., 2007). Furthermore, in cases where external pressure is discontinuous, such as wildfires, large erosion events caused by flood events, etc., sudden shifts can be anticipated. A relatively recent large scale example of discontinuous change in the Mediterranean is the deforestation of central Crete before the end of World War II (Hostert et al., 2003). In smaller scales, similar phenomena are observed at restored Mediterranean forests that after numerous fire occurrences have lost resilience and subsequent restoration *sensu latu* is never finished, as some maintenance is always required. In both systems, strong feedbacks between biotic factors and the physical environment can signify the existence of localized thresholds. These thresholds can either depict a “point of no return” or a “resilience against restoration” owing to constrains or in the vegetation-soil system at landscape level. Whereas for continuous pressure, thresholds may be sought in the combined effect of a secondary pressure, in the case of discontinuous events, thresholds relevant to event frequency and intensity are possible key indicators (Twidwell et al., 2013). These thresholds are often associated with target species physiology, landscape and climatic characteristics and can be expected to have a localized effectiveness, although, emerging patterns can potentially evolve into a unifying framework. Drivers of desertification in the CASCADE Study Sites within such a framework will be investigated further in Deliverable 2.2.

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# Appendix I – Remote Sensing indices

**Non-parametric indeces relevant to vegetation applications that can be applied for all current LandSat sensors (LandsatETM+ (Landsat7), LandsatMSS (Landsat1-3), LandsatTM (Landsat4,5))**

| No | Index Name | Abbrev. | Definition | Reference |
|---|---|---|---|---|
| 1 | Ratio Vegetation Index | RVI | $\frac{\rho_R}{\rho_{NIR}}$ | Person and Miller, 1972 |
| 2 | Vegetation Index Number | VIN | $\frac{\rho_{NIR}}{\rho_R}$ | Person and Miller, 1972 |
| 3 | Green Ratio Vegetation Index | GRVI | $\frac{\rho_{NIR}}{\rho_G}$ | Gitelson et al., 2002 |
| 4 | Differenced Vegetation Index MSS | DVIMMS | $2.4\rho_{NIR} - \rho_R$ | Richardson and Weigand, 1977 |
| 5 | Ashburn Vegetation Index | AVI | $2\rho_{NIR} - \rho_R$ | Ashburn, 1979 |
| 6 | Normalized Difference Vegetation Index | NDVI | $\frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R}$ | Deering and Haas, 1980 |
| 7 | Chlorophyll Index Green | Clgreen | $\rho_{NIR}/\rho_G - 1$ | Peng et al., 2011 |
| 8 | Chlorophyll IndexRedEdge | Clrededge | $\rho_{NIR}/\rho_R - 1$ | Peng et al., 2011 |
| 9 | Global Environment Monitoring Index | GEMI | $n(1 - 0.25n) - \frac{\rho_R - 0.125}{1 - \rho_R}$ <br> $n = \frac{2({\rho_{NIR}}^2 - {\rho_R}^2) + 1.5\rho_{NIR} + 0.5\rho_R}{\rho_{NIR} + \rho_R + 0.5}$ | Pinty and Verstraete, 1992 |
| 10 | Green Normalized Difference Vegetation Index | GNDVI | $\frac{\rho_{NIR} - \rho_G}{\rho_{NIR} + \rho_G}$ | Buschmann and Nagel, 1993 |
| 11 | Green-Red NDVI | GRNDVI | $\frac{\rho_{NIR} - (\rho_G + \rho_R)}{\rho_{NIR} + (\rho_G + \rho_R)}$ | Wang et al., 2008 |
| 12 | Soil Background Line | SBL | $\rho_{NIR} - 2.4\rho_R$ | Richardson and Weigand, 1977 |
| 13 | Spectral Polygon Vegetation Index | SPVI | $0.4[3.7(\rho_{NIR} - \rho_R) - 1.2\lvert\rho_G - \rho_R\rvert]$ | Vincini et al., 2006 |

| | | | | |
|---|---|---|---|---|
| 14 | Nonlinear Vegetation Index | NLI | $\frac{\rho_{NIR}{}^2 - \rho_R}{\rho_{NIR}{}^2 + \rho_R}$ | Goel and Qin, 1994 |
| 15 | Normalized Difference Red/Green Redness Index | RI | $\frac{\rho_R - \rho_G}{\rho_R + \rho_G}$ | Escadafal and Huete, 1991 |
| 16 | Renormalized difference vegetation index | RDVI | $\frac{\rho_{NIR} - \rho_R}{\sqrt{\rho_{NIR} + \rho_R}}$ | Roujean and Breon, 1995 |
| 17 | Simple Ratio | SR | $\frac{1 + NDVI}{1 - NDVI}$ | Chen, 1996 |
| 18 | Modified Simple Ratio | MSR | $\frac{\sqrt{2}NDVI}{\sqrt{1 - NDVI}}$ | Chen, 1996 |
| 19 | Normalized Difference Green | NGRDI | $\frac{\rho_G - \rho_R}{\rho_G + \rho_R}$ | Gitelson et al., 2002 |
| 20 | Modified Triangular Vegetation Index 1 | MTVI1 | $1.2[1.2(\rho_{NIR} - \rho_G) - 2.5(\rho_R - \rho_G)]$ | Haboudane, 2004 |
| 21 | Modified Triangular Vegetation Index 2 | MTVI2 | $\frac{1.5[1.2(\rho_{NIR} - \rho_G) - 2.5(\rho_R - \rho_G)]}{\sqrt{(2\rho_{NIR} + 1)^2 - \left(6\rho_{NIR} - 5\sqrt{\rho_R}\right) - 0}}$ | Haboudane, 2004 |
| 22 | Modified Chlorophyll Absorption in Reflectance Index 1 | MCARI1 | $1.2[2.5(\rho_{NIR} - \rho_R) - 1.3(\rho_R - \rho_G)]$ | Haboudane, 2004 |
| 23 | Modified Chlorophyll Absorption in Reflectance Index 2 | MCARI2 | $\frac{1.5[1.2(\rho_{NIR} - \rho_R) - 2.5(\rho_R - \rho_G)]}{\sqrt{(2\rho_{NIR} + 1)^2 - \left(6\rho_{NIR} - 5\sqrt{\rho_R}\right) - 0}}$ | Haboudane, 2004 |
| 24 | Modified Soil Adjusted Vegetation Index 2 | MSAVI2 | $0.5\left(2\rho_{NIR} + 1 - \sqrt{(2\rho_{NIR} + 1)^2 - 8(\rho_{NIR} - \rho_R)}\right)$ | Qi et al., 1994 |

where $\rho_i$ is the reflectance for different bands (R, G, B, NIR)

# Appendix II – Data Availability Questionnaire

| General Information | |
|---|---|
| **Study site:** | |
| **Country:** | |
| **Institution:** | |
| **Contact person (name):** | |
| **Contact person (email):** | |

### Introduction

The objective of this questionnaire is to allow for a clear overview of the data availability of your Study Site, its spatial and temporal resolution and any significant metadata that should be accompany datasets.

When filling the following tables, keep in mind that:

1. The preferred format for spatial data is an arcgis compatible shape (shp) or grid file. Data can be stored with a WGS84 projection but a local projection is expected to be available for calculations (e.g. area calculations)
2. The preferred format for point data is an excel file. Point data consist of an equally spaced time series including the point of measurement (lat, lon) and units for each variable.
3. Metadata can include various information significant for the dataset interpretation, e.g. spatial data resolution and projection system, point data spatial support (for example point or spatially averaged value, etc.)
4. The status of each dataset can be public or restricted, etc., depending of inherent rights, any legal or other restrictions of use, or the need to acknowledge the source.
5. Since this WP is related to "evolution", a process through time, datasets (point or spatial) in the form of time series are more valuable that single valuables instances or valuables that can be considered stationary altogether.

### Part I – Spatial Data

Accurate spatial definition is a staple for successfully framing the study site description. While spatial data is often freely available at a course resolution, detailed datasets can be easier to link with small scale experiments (e.g. WP3) and should be provided when possible. If a watershed is not adequately defined and the digital elevation model (DEM) is not available, it will be extracted from the publicly available SRTM dataset provided the (lat, lon) of the watershed's outlet.

| Spatial Coverage | Available | Metadata | Status |
|---|---|---|---|
| Watershed outlet location (lat, lon) | | | |
| Shape file available | | | |
| Digital elevation model (DEM) | | | |
| Land Use Map (arcgis compatible grid) (alternatively CORINE 1990/2000/2006) | | | |
| Digital Soil Map (arcgis compatible grid) (alternatively data from the European Soil Database) | | | |
| Geological maps | | | |

### Part II – Hydro-meteorological Data

Apart from the estimation of trends and other statistical characteristics, hydro-meteorological time series can be used to extract various drought indexes.

| Hydro-meteorological Data | Location | Metadata | Status |
|---|---|---|---|
| Precipitation | | | |
| Temperature | | | |
| Evapotranspiration | | | |
| Potential Evapotranspiration | | | |
| Groundwater level | | | |
| Flow/Runoff | | | |
| Stage | | | |

### Proposed Soil-Vegetation Systems

Add a short description of possibly more than one dryland ecosystem where the CASCADE project can be focused on.

| Soil Type | Vegetation | Location |
|---|---|---|
| | | |

### Part IV – Soil Data

| | | | |
|---|---|---|---|
| Salinity Measurement | | | |
| Soil Moisture | | | |
| Soil pH | | | |
| Soil $CaCO_3$ | | | |
| Soil organic matter | | | |
| Available Water Capacity (AWC) | | | |
| Irrigation | | | |
| Application of fertilizers/pesticides | | | |
| Spectroradiometer measurements | | | |

### Part IV – Vegetation Data

| | | | |
|---|---|---|---|
| Vegetation/crop type | | | |
| Chlorophyll | | | |
| Leaf Area Index (LAI) | | | |
| Vegetation Cover | | | |
| Biomass/production | | | |
| Yield (production/area) | | | |
| Biodiversity (Richness/Evenness) | | | |

### Part V – Livestock Data

Free-range livestock can, over time, degrade rangelands due to overgrazing. The rate of degradation depends again of the density of the livestock population and the restoration rate of the natural flora.

| Livestock Data | Available | Metadata | Status |
|---|---|---|---|
| Livestock Type | | | |
| Livestock population/density | | | |
| Flora types grazed | | | |

| | | | |
|---|---|---|---|
| Managed/unmanaged | | | |

### Part VI – Remote Sensing Data

While archived Remote Sensing datasets over your study area can possibly be found in the public domain (USGS LandSat imagery) or are inexpensive at low spatial resolutions (SPOT, ASTER), it is hard to establish a dataset with a long time axis. Moreover, no satellite imagery is available before 1970. Therefore, any additional input (e.g. aerial photos, archived satellite imagery) will be useful to enrich the study site description and establish its historical background.

| Remote Sensing Product | Available | Metadata | Status |
|---|---|---|---|
| Aerial photography | | | |
| 2-weekly air temperature maps | | | |

### Part VII – Socioeconomic Data

The indirect anthropogenic drivers of change in drylands are diverse and act on several scales. They include demographic drivers, such as local population growth or immigration resulting from regional population growth; economic drivers, such as local and global market trends; and sociopolitical drivers, such as local and regional land tenure policies as well as scientific and technological innovations and transfer.

| Socioeconomic Data | Available | Metadata | Status |
|---|---|---|---|
| Population | | | |
| Population density | | | |
| Population occupation (urban/rural etc) | | | |
| GDP | | | |
| Human Development Index | | | |
| Human Poverty Index | | | |

### Part IX– Event Timeline

An event timeline needs to be established in order to identify abrupt shift, changes in trends etc. The temporal resolution of the timescale (years, months, days, etc.) depends on the particular event that needs to be depicted.

| Time | Event | Consequence |
|---|---|---|
| | | |