ENVIRONMENTAL ASSESSMENT OF AN ARCHAEOLOGICAL SITE FOR THE DEVELOPMENT OF AN ARCHAEOLOGICAL PARK

Paola Rossi Pisa, Gabriele Bitelli, Marco Bittelli, Maria Speranza, Lucia Ferroni, Pietro Catizone, Marco Vignudelli

Abstract

In this work we present a general description of techniques used to perform an integrated environmental assessment of an archaeological site, for the development of an archaeological park. The case study of Tilmen Höyük, an archaeological excavation in South-East Turkey, is presented to describe the combination of different integrated approaches. The site has been assessed from a climatic, topographical, pedological, hydrological, vegetational and vegetation management standpoint. All this information was included into a Geographic Information System, and used to define a management protocol. The present protocol is suitable to be used in other archaeological sites of the Mediterranean basin, since many climatic, environmental and vegetational features are often shared by different sites. This study provided a wealth of information that was used for both acquiring a deeper understanding of the past and present societies, but also to design and plan the archaeological park.

1. INTRODUCTION

Archaeological sites are non-renewable resources that provide researchers with unique information on people and civilisations of the distant past, but also serve as valuable ecological and aesthetic assets that can enhance urban and rural environments.

Traditionally, archaeological sites have been considered only for their historical and cultural aspects, without attributing any particular importance to the environmental context or to the landscape in which they are found. Increasingly, however, such sites are being considered natural and ‘cultural landscapes’ (Von Droste et al. 1995, Clavel-Lévêque 2001), or ‘open spaces of variable sizes, structured on a geo-historical space and around a specific theme from a central reference: an archaeological area or a site’ (Clavel-Lévêque et al. 2002).

The relationships between archaeological structures and living organisms (lichens, fungi, cyanobacteria or plant communities) have traditionally focused on the deterioration that these can cause to archaeological structures, compromising their conservation and accessibility (Speranza et al. 1993, Caneva et al. 2003, Lisci et al. 2003). As an integral part of the site ecology, vegetation should be examined for possible usage patterns as an important landscape design element, and managed with well planned vegetation management and, if necessary, weed-control.

In this paper we outline an integrated and holistic approach toward the planning and protection of archaeological sites, taking into consideration the physical landscape and biological environment around them (Celesti-Grapow and Blasi 2004, Sánchez-Palencia and Højring 2002). Such a multi-pronged, cross-disciplinary approach helps formulate better site management while conserving and sustaining the site’s archaeological structures and environmental resources.

As conservation and site management become more multi-disciplinary, skills and knowledge beyond the traditional confines of archaeology will play an increasingly important role, especially in the ability to use instruments and alternative methods of territorial analysis. When archaeological sites are examined as ‘archaeological landscapes’ it is important to define the concept of heritage, heritage protection and heritage management (Mosler 2007). Heritage is defined as a valuable feature of the past that is being protected for the next generations, implying not only the preservation of cultural remains but also of natural and ecological resources that help define the ‘sense of place’ of a site. Mosler (1995) suggested that heritage be more specifically articulated using the terms preservation, conservation and reconstruction. Preservation maintains the archaeological remains in its existing state and the actions are aimed at mitigating future damage. Conservation includes all the processes coming after preservation such as restoration, adaptation and maintenance. Reconstruction involves a complete or partial rebuilding of a heritage on firm or supposed evidence of the original setting of a place. According to Mosler (1995), reconstruction should almost always be avoided, since it often involves a fictional, personal interpretation by the archaeologist. Tuchelt (1996) critically discussed that, after excavation, the desire to recreate the sense of heritage can lead to the creation of a souvenir value of ancient heritage. Indeed, the definition of what constitutes ‘authenticity’ is increasingly a point of discussion, especially as it relates to cultural tourism (Poria et al. 2003). Authenticity is perceived as a lack of alteration of the original landscape and Cultural Heritage. Chhabra et al. (2003) suggested that authenticity can be achieved even when the original source does not exist anymore, and that past events may be valued even if the physical traces are no longer present.

A thorough understanding of the environment is key to understanding and preserving the original culture and natural features of the site, where topography, vegetation, water, architectural structures and artefacts all play a role in determining the landscape. However, integrated environmental assessment is also an important component in the development of an archaeological park that is environmentally
sustainable and practical to maintain, while still preserving authenticity, emphasising the surrounding natural beauty and creating a pleasant, informative and manageable park for visitors.

In this paper we present a case study at the archaeological excavation of Tilmen Höyük, in South-Eastern Turkey. The project presents a multidisciplinary approach for a full assessment of the park from numerous points of view. The aim of this study was to employ integrated strategies for reducing damage to the surrounding environment by the excavations, while enhancing the existing environmental features of the surrounding habitat. The study included climate, topography, soil, hydrology, vegetation, weed control and site management. Finally, this integrated information was stored, analysed and interpreted using a Geographic Information System (GIS).

2. CLIMATE
(Paola Rossi Pisa)

The climate of an area, site or region determines many factors that can shape human society. The type of natural and cultivated plant species in an area affects dietary habits and food preparation, which in turn influence food storage and transport. The type of natural and cultivated plant species in an area affects dietary habits and food preparation, which in turn influence food storage and transport.

2.1 Precipitation

Precipitation is concentrated in the fall and winter season, with annual rainfall of 900 mm and mean annual air temperature is 16°C. The low average temperature during winter months indicates that below freezing temperatures are common.

2.2 Temperature

Today, the climate at Tilmen Höyük (Fig. 1) is continental, with hot summers and cold winters, as indicated by the Bagnouls and Gaussen diagram (Bagnouls and Gaussen 1957), which shows the occurrence of the dry and wet periods (when precipitation in mm is less or equal to twice the temperature in Celsius degrees). The intersection of the rainfall and temperature curves defines the extent of the dry period, typically May-September. Annual rainfall is 900 mm and mean annual air temperature is 16°C. The low average temperature during winter months indicates that below freezing temperatures are common.

Precipitation, air temperature, wind velocity and direction, atmospheric pressure, global solar radiation and relative humidity were measured by automated stations. Data were collected by data loggers and post-processed to obtain hourly and daily values of the measured variables. Fig. 2 depicts (a) daily cumulative precipitation and average air temperature, and (b) average daily global solar radiation and relative humidity for the year 2007. Cumulative precipitation is concentrated in the fall and winter season with almost no precipitation during the summer months. Average daily temperature also depicts a climate characterised by cold winters (note that average temperature is below zero for a few days during December and January) and hot summers with average temperatures often above 30°C. Wind direction was computed by trigonometric daily averages of 15 minute measurements, therefore providing a detailed characterisation of wind dynamics at the site (Fig. 3). The 360° (or 0°) corresponds to wind blowing from the north, while 45° corresponds to wind blowing from north-east, 90° from east and so forth. The arrows indicate wind speed peaks and corresponding wind direction. Overall wind speed at the site (during 2007) was relatively low with a maximum speed of 6.18 m s⁻¹ on February 3rd, and average annual speed of 2.34 m s⁻¹. The dominant direction for average wind speed was 360° corresponding to north, however, the dominant direction changed when wind speed increased, with the direction from north-east (45°) as shown by the arrows. In some cases the increased wind direction corresponded to precipitation events, indicating weather fronts from the north-east Anatolian region.

2.3.2 Wind direction

Today, the climate at Tilmen Höyük (Fig. 1) is continental, with hot summers and cold winters, as indicated by the Bagnouls and Gaussen diagram (Bagnouls and Gaussen 1957). The architecture team used wind velocity information gleaned from this study to design some light structures necessary for protecting some of the fragile, exposed, excavated areas (Musso, this volume). Indeed, the relatively high precipitation amount (900 mm year⁻¹) poses a serious water erosion risk to walls and structures built with mudbricks. The areas where basaltic rock was used for foundations and main walls are more resistant to wind and water erosion and therefore did not require any particular protection.

3. TOPOGRAPHY AND SURVEYING
(Gabriele Bitelli)

Study and management of an archaeological area and its territory requires a rigorous topographical and cartographical characterisation in order to obtain the correct georeferences. The surveying procedures could have been designed and set up in many different ways. For instance, the survey could focus on local precision and high resolution, collecting the best quality data ‘relative’ to the local position but without a good ‘absolute’ positioning, or the survey could aim at acquiring good ‘absolute’ positioning by obtaining well determined cartographic coordinates, or both.

For the site of Tilmen Höyük, the latter approach was followed, integrating modern geomatic techniques and technologies. This provided good metric knowledge of the site, including 3D relationships between single structures or parts of the city, but also good contextual, cartographic information, useful for studies at a larger level (e.g., at regional level). The core technique was the Global Positioning System (GPS). GPS measurements were carried out by geodetic instruments (single and double frequency) using different methods for different aims:

• Absolute positioning was performed by static measurements of long duration (spanning many hours) and subsequent processing of these data together with data coming from independent GPS permanent stations (baselines up to hundreds of kilometres) in the ITRF2000 system. A main reference station was established at an open position at the top of the city.
Local surveys were performed by a rapid-static method for establishment of other stations with a precision at the centimetre level or in kinematics form (in this case, the antenna is moving and the coordinates refer to points along a path): the first was applied to institute secondary vertices in the area, the second for the positioning of geophysical surveys and to obtain a large number of distributed points with 3D coordinates, to derive a good morphology description.

GPS ellipsoidal heights were subject to geoidal undulation corrections by using a global model. All the planimetric data were provided in UTM-WGS84 fuse 37. Local description of the morphology and structures was then performed by topographical surveying using a total station, with reference points determined by GPS. In this way, an accurate description of the structures and determination of the digital terrain model of the site were achieved, developing a 3D system of coordinates usable also at a cartographic level, without being limited by a local network and reference system. Similarly, the use of GPS derived Ground Control Points (GCPs) permits the 3D models and data derived from photogrammetric surveys to be inserted into the cartographic system. They were carried out by semi-metric or calibrated digital cameras positioned on some structures of interest, following conventional schemes of picture recording and image acquisition.

The contextualisation of the site in the framework of its territory is obviously of great importance for a multidisciplinary study. To have a wide picture of the area, imaging systems are the most appropriate choice, in particular through aerial photogrammetry or the use of Remote Sensing sensors and platforms (Fig. 4). Accurate georeferencing and geocoding of these datasets can support a well-defined analysis of the region and its evolution. Optical imagery from satellites, in panchromatic or in multispectral arrangement, was used at different levels of geometric and spectral resolution. Very high resolution imagery can provide sub-metre ground resolution in panchromatic, useful for deriving orthoimages at large-medium scale, and can support photo-interpretation processes with high detail. In this case, Quickbird images with sub-metre pixel size were used for Tilmen Höyük, and georeferencing was obtained using a Rational Polynomial Function (RPF) model supported by ground control points obtained by GPS on-site measurements. Medium resolution images (Landsat, ASTER, etc.) are used for multispectral classification, providing the essential data to derive thematic maps for the overall region with pixel size in the order of 15-30 m. Stereoscopic satellite data were also used to derive a digital terrain model for a very large region, using automatic matching procedures. Radar data products were used adopting a Shuttle Radar Topographic Mapping (SRTM) model as a base for topographical analysis of the region; the SRTM model was compared with the one obtained by ASTER stereocouples, confirming an overall quality in the heights in the order of 15-20 m. Further use of radar data is expected. Finally, an attempt is under way to use some declassified images from the Corona mission for metrical purposes. The images were acquired for military purposes but are now being made available to the civilian community. With these images, change detection procedures can be performed with good geometrical resolution. Their processing, however, is not obvious due to the panoramic mode adopted by the sensor and the lack of knowledge about geometrical and calibration data, neither for the camera, nor for the satellite platform.

4. SOIL AND HYDROLOGY

(Marco Bittelli)

A soil analysis within an archaeological excavation is performed for several reasons: to reconstruct history of the site, to understand present and past vegetation, and to plan the management of the park. Often, the soil chemical composition is an indication of specific processes that occurred at the site, such as water lodging, human or animal bone decomposition, dietary indications and so forth. At Tilmen Höyük, investigation of soil properties was performed through drilling, core sampling and collection of disturbed and undisturbed soil samples at different points. Numerous physical and chemical properties were measured: sand, silt and clay content, calcium carbonate, potassium, nitrate, cation exchange capacity, salinity, pH and organic matter. The samples were:

a. collected at the location displayed on the site map (Fig. 5),
b. georeferenced by using a portable GPS,
c. numbered to assign an identification number (ID) and
d. integrated into a Geographical Information System.

The dominant textural classes are loam, silty-loam and clay-loam. Considering that the bedrock is a coherent basalt deposit, and that the area is of small aerial extension, these variations in textural composition may also be due to human activity over the years, as well as natural phenomena such as soil-water erosion and weathering. The soil presents a relatively high content of nutrients and organic matter, facilitating the growth of many plant species and indicating the presence of grazing. Soils at Tilmen Höyük are naturally fertile but vulnerable to erosion because of the shallowness of the soil to basalt bedrock, as indicated by a soil survey and visible bedrock outcrops. During the soil survey, high concentrations of phosphorus and potassium were found in respect to average soil concentrations of these elements under natural conditions in similar environments. Phosphorus (P₂O₅) concentration ranged from 100 to 300 ppm, with an average of 219 ppm, while total potassium ranged from 220 to 2553 ppm with an average of 1105 ppm. High CaCO₃ was also detected, indicating a possible accumulation of ash due to past burnings, since CaCO₃ is the most dominant component of ash. The lack of strong alkaline conditions also indicates that the soil does not experience salt accumulation near the soil surface, usually due to high evaporation rates fed by a shallow groundwater. This is explained by the deep level of the groundwater in the upper part of the mound and by the good drainage of the soil. This is also confirmed by the neutrality or close to neutrality values of pH indicating aerobic conditions at the site, which indeed is well drained and does not favour water lodging or reducing conditions. The site was investigated hydrologically to identify the position of the groundwater level and the dynamics of soil water. The mound is surrounded on the west, east and...
north side by a small and shallow river. The reservoir on the north side is artificial, built recently for the irrigation of surrounding agriculture. The river, however, is part of the natural setting, and it probably still follows its natural course. These two water bodies allowed the establishment of a rich and diverse environment comprising a large variety of plants, species, animals, and insects. The site itself is positioned at a higher altitude than the surrounding area, the soil is permeable and well drained, and therefore the groundwater level is determined by the river and reservoir. A Ground Penetrating Radar (GPR) was used to identify groundwater depth in the south-east part of the city. In particular, Fig. 6 depicts the water table level in front of gateway K-6. The water table is shallow (130 cm ca) and is determined by the river in the north-eastern part. The water table tends to become deeper while moving in a south-westly direction, due to the farther distance from the river.

5. VEGETATION
(Maria Speranza, Lucia Ferroni)

Landscape is strongly characterised by the vegetation cover, which depends on how different species are aggregated in specific local communities. There are three different hierarchical levels, each contributing to the overall value of the territory. The first is represented by the different plant species that constitute the flora of a given territory. The second by the plant communities that are the result of the different possible combinations of species of the flora influenced by varying environmental factors. The third level is represented by the landscape, in other words, the reciprocal arrangement of plant communities in spatial and functional relationships. All three components should be considered in a conservation and management project.

5.1. The flora

The flora can be investigated by analysing small sampling areas following a homogeneous scheme, for which partial species lists are compiled. These lists are then merged into one overall list (flora), which includes all the species found in the investigated territory. The plant list is first analysed to provide an initial general overview of the analysed territory. The aspects are usually the floristic biodiversity, the dominance of particular botanical families, the presence of rare and/or endemic species, the presence of particular phyto-geographical elements, and the presence of disturbed environments and/or invasive species. For a sustainable management of an archaeological site, the study of the flora represents an important general framework for planning conservation and control actions.

At Tilmen Höyük, the phyto-geographical analysis of the flora allowed us to classify the site within the Mediterranean framework with Eastern-Mediterranean and Irano-Turanian elements. The study of the flora, moreover, highlighted a remarkable taxonomic diversity (221 different plant taxa in an area of 25 ha), and a prevalence of the botanical families of Asteraceae, Fabaceae and Poaceae, as in the flora of the whole Turkish territory and many Mediterranean areas. Particularly significant was the specific diversity of the genus *Trifolium* (Fabaceae family) which, in the small Tilmen area, is present with 15 different species. The floristic study further emphasised the great interest of the site from the point of view of the presence of rare taxa endemic to the nearby Amanus mountains (e.g., *Cerasus microcarpa* subsp. *tortuosa*, *Salvia indica*, *Carduus rechingeranus*, *Onopordum boissieri*, *Trifolium aintabense*, *Erodium micropetalum*, *Alcea apterocarpa* and *Rumex amanus*). Pl. XI: 3 shows three endemic species of the Tilmen flora. Among the flora of many Mediterranean archaeological sites, and in particular those of the East-Mediterranean, wild ancestors of some Old World cultivated plants are often present. Their presence should be pointed out to visitors, since they reflect the relationship between human history and the natural environment. At Tilmen several wild ancestors were found: *Hordeum spontaneum*, *Aegilops biuncialis*, *Pisum sativum* subsp. *elatius*, *Vitis vinifera* subsp. *sylvestris*. The domestication of *Hordeum spontaneum* in the Fertile Crescent area gave rise to *Hordeum vulgare* (cultivated barley), the oldest cereal of Old World agriculture, dating back to 10,000 years BP. Much more recent is the domestication of *Ficus carica* subsp. *rapetris* (wild fig tree), *Olea europaea* var. *sylvestris* (wild olive tree) and *Vitis vinifera* subsp. *sylvestris* (wild grapevine), which started in the Early Bronze Age and developed in the Middle and Late Bronze Ages, coinciding with the most important periods of occupation at Tilmen.

5.2. The vegetation

Plants communities (collectively named vegetation) are ensembles of species of the flora of a given territory that are determined by the specific local combination of environmental factors. The repeated presence of a given plant community in different parts of the same territory corresponds to a repeated combination of the same environmental factors. The spatial distribution of different plant communities indicates discontinuities and heterogeneities in the spatial distribution of the environmental conditions. The plant communities growing in an archaeological site can help to identify the different environmental conditions and, consequently, help define different management approaches to best preserve, modify or suppress them. In general, stronger containment interventions or the elimination of plant communities (with weed control) must be reserved to communities that grow in direct contact or close to the archaeological structures, threatening their integrity and full enjoyment, while the rest should be left in its natural state. Usually, such intervention involves herbicides and the development of protocols for the doses and times for such treatment, depending on the climatic characteristics of the site and the specific composition of the plant communities to be controlled.

Equally important is the management of the plant communities growing in recently excavated areas. Once excavation is finished, it is generally desirable to enhance vegetation cover in these areas. However, this cover should have different characteristics from the naturally formed communities that are recolonising areas severely disturbed more recently, following destruction of antecedent vegetation. In fact, in these new communities, where one or few species can be dominant, prickly and thorny annuals prevail.
Such communities are not particularly environmentally interesting, since they are the expression of a typically anthropogenic disturbance. Moreover, these communities are not even pleasing from an aesthetic point of view, because the predominance of annuals means that the plants are dry throughout the period of the long Mediterranean summer. Excavation should be done with caution, avoiding, for instance, the complete destruction of existing vegetation, ensuring temporary storage (until the end of the excavation) of the removed soil and especially the first soil layer, that contains seeds and vegetative propagules (parts of rhizomes or stolons). This material can be used to close the excavated area in an attempt to trigger a more rapid restoration process of the pre-excavation plant communities.

Containment interventions, usually less harsh than those used in the areas occupied by archaeological sites, should be reserved to those communities along pathways within the archaeological area. For these situations only mechanical interventions may be scheduled, combined with appropriate chemical herbicide.

Finally, plant communities less directly related to the archaeological structures and the site pathways should not be subject to interventions but to preservation and restoration measures. These plant communities usually represent the greatest interest from a naturalistic environmental point of view, as they are less subject to anthropogenic disturbance and are closer to sub-natural conditions. Their presence also enhances the site aesthetically.

At Tilmen Höyük, the plant community analysis highlighted the environmental diversity of the site, where at least six different types of plant communities were recognised. The plant community analysis revealed that the most critical areas for development of management protocols are the recently excavated areas, where poorly covering plant communities have developed, mostly made up of annual herbaceous species (Centaura solstitialis, Lactuca serriola, Chondrilla juncea, Trifolium purpureum, Aegilops biuncialis, Aegilops triuncialis). The management of these areas, where not occupied by archaeological artefacts, should encourage the formation of more balanced plant communities, with the presence of perennial herbaceous plants and some woody species (Styrax officinialis, Loniceria etrusca, Crataegus curvisepala, Palirus spina-christi), which stay green during the summer. These kinds of communities are already present in the less recent excavation areas where the endemic species Alcea apterocarpa finds its habitat.

Pl. XII: 2 shows two different habitats present in the Tilmen Höyük area: Salix acmophylla igrophilous community along a little river (left) and Quercus cocifera dry shrub land (right).

Finally, the vegetation analysis also identified the most interesting naturalistic-environmental areas, where site management protocols should aim for the maintenance and preservation of the corresponding plant communities. These are the areas occupied by hygrophilous communities along watercourses or by wetland communities, or by shrublands and open woods, where two important East-Mediterranean Quercus species are present: Quercus cocifera and Quercus brantii, and where, in more protected, less dry stations, Ficus carica subsp. rupestris, the wild fig tree, is present.

5.3. The plant landscape

The plant landscape is the spatial distribution and aggregation of the various plant communities in a given territory. In the Mediterranean, the landscape reflects a long history of a strong anthropic presence and plant cover disturbances from human activities. Overgrazing, agriculture and clearing have shaped the landscape, sometimes strongly simplifying and reducing the diversity of its components. In addition, in archaeological sites, the excavation activities have often introduced new disturbances.

In the management of an archaeological site, it is important to take into account the overall characteristics of the plant landscape and its variability. Despite the fact that diversified landscapes are generally more pleasant than uniform and monotonous landscapes, the management and utilisation of an archaeological site should never introduce important elements of diversification that contrast with the existing landscape, but should only build upon the diverse environmental elements already present.

The infrastructures necessary to make the site usable by the public must be kept to a minimum and should fit into the plant landscape with shapes, sizes and volumes that are similar to the local traditional buildings, never dominating the historical-archaeological buildings.

Plant species to be included in the areas welcoming visitors should be chosen from those that most appropriately characterise the local plant landscape. This requires close cooperation between plant ecologists and landscape ecologists on the one hand, and architects on the other.

The archaeological site of Tilmen Höyük is set within a landscape that has managed to retain all its somewhat archaic charm, due to the great open spaces surrounding it, and very discreet human presence, which is felt only indirectly.

Considered on a large scale, the landscape is quite homogeneous, but on a more detailed scale it offers several points of diversification, thanks to the presence of an interesting system of water bodies and waterways, particularly appreciable during the dry summer period. At present there are no new buildings in the area, only the ancient city remains. These ruins, given their archaeological and historical value, must play a key role in the site landscape, as shown in Pl. XII: 2. Appropriate vegetation containment will keep the ancient buildings free from plants, allowing them to stand out better as the only anthropic elements dominating the landscape. But an equally important role is played by the surrounding plant landscape, and in particular by the more natural plant communities, which represent the best framework for this archaeological site.

6. WEED CONTROL

(Pietro Catizone)

In general, the herbicides used in an archaeological site should be of low toxicity for humans and animals, have low environmental transferability and not impact the archaeological remains. Many species are propagated trough seeds; therefore, the weed management should include a long-term intervention aimed at reducing hot spots by a residual effect, which prolongs the herbicide effect by re-
mainly active for longer periods in the soil. Usually, weed management includes an initial treatment over flora never treated before, and then a maintenance treatment to keep the plant population under control. Initial treatment can be performed with residual herbicides (terbutylazine and oxadiazion), which stay active in the soil for longer periods and limit seed germination. It is then suggested to use herbicides applied to leaves, which moves through a symplastic transport (glyphosate and glyphosate-trimesium). Usually, the initial application should be performed at the beginning of the winter, while the secondary application should be applied 2-4 times throughout the year. The control of trees and shrubs is also important in archaeological sites, since their roots can be quite disruptive for archaeological remains. Table 1 (from Miravalle et al. 2001) describes the main herbicides to be used based on the dominant plant populations.

The annual herbicide application for herbaceous plants should be performed when the species plant has completed emerged (usually between November and April for the northern hemisphere). However, it is sometimes suggested to combine a post-emergence treatment with a residual, full spectrum herbicide. In general, it is better to intervene early on, on relatively small biomasses. Also for perennial species, if possible it is suggested to apply the herbicide on small biomasses, aiming at preventing an excessive growth, which is more difficult to control. To control Rubus spp., Clematis and canes (Arundo donax and Phragmites australis), an uprooting treatment should be performed with systemic herbicides able to be transferred to the roots. The management of a controlled grass cover, for aesthetic purposes within the archaeological park, can be achieved by using selective herbicides, allowing only specific species to develop. For instance, for a robust, resilient grass coverage, Cynodon dactylon and Trifolium fragiferum (perennial) were suggested for the Tilmen site, where they are naturally associated.

From the vegetation analysis at Tilmen Höyük, it appeared that weed control had to be performed both on annual and perennial plants, therefore it was necessary to use chemicals able to enter through both leaves and roots. Weed control included the use of full spectrum herbicides to eliminate all the vegetation on the archaeological buildings and on the visitors pathways (cf. Fig. 3 in Marchetti, this volume). For this kind of application symplastic herbicides were used such as glyphosate and glufosinate.

7. INTEGRATION INTO A GEOGRAPHICAL INFORMATION SYSTEM
(Marco Vignudelli)

In a multidisciplinary approach of this kind, the various aspects to be considered can be best described and investigated in terms of their spatial extension and their spatial distribution using the formal structure of Geographical Information Systems (GIS). These systems have the advantage of allowing the creation of thematic databases, which can be usefully superimposed and crossed according to the different aspects being considered. All the information described above was incorporated into a GIS. All the spatial data taken at Tilmen were georeferenced to the WGS84 Datum UTM 37 Coordinate System and have been managed by the software Arcview 3.2 (ESRI Inc.) and its extension, 3D Analyst. Many different thematic layers have been created: topography, vegetation clusters, archaeological excavations, tourist trails, information panels, 3D relief. All these layers are linked with their own attribute table, so that it is possible to create a continuous update of the information, particularly important and useful for the dynamic element of vegetation. When dealing with a complex environmental site with many variables, a Geographic Information System represents the best approach for integrating different data into one instrument (Pl. XII: 3).

8. SITE MANAGEMENT
(Paola Rossi Pisa)

The integrated information collected by employing the different techniques described so far, should be used not only for obtaining a better understanding of the archaeological site, but also for a better planning and preservation of the archaeological park. This information will be transferable to other situations (up-scaling) in the Mediterranean area. The archaeological site should maintain vegetated areas, which represent the equilibrium between the soil and the biodiversity, both for plants and animals. Agronomic techniques should be performed with the minimum disturbance within the excavation area and surrounding landscape, to preserve the natural life in the archaeological park. It is highly suggested that the uppermost layer of fertile soil and its seed bank be preserved during excavation in order to cover other excavated areas, and re-establish plant population. Often, the soil is excavated, mixed and repositioned without preserving its original layering. This practice usually results in positioning soil of bad quality on the top layer, with subsequent difficulties for re-establishing plant population, because of lack of organic matter, nutrients, and reduced water holding capacity.

During the development of the archaeological park, nature trails (Pl. XIII: 1) were developed with the aim of coupling the archaeological and naturalistic interests of the site, including topographic, vegetational and hydrological features. Specific information panels were designed and installed along the nature pathways, with information about climate, geology and vegetation: texts explain the evolution and relationships between man and his environment across different historical periods.

9. CONCLUSIONS

In recent decades, the definition of heritage preservation acquired a broader meaning, including the concept of ‘cultural landscapes’ and ‘archaeological heritage conservation and management’. While in most cases the archaeological remains still characterise the dominant aspect of interest, the archaeological site should also be valued for its climatic, geological, environmental and vegetation features. The integration of these different aspects leads toward a broader concept of cultural landscape, where archaeologi-
cal parks are not just an isolated feature of the landscape but rather serve an interactive role in environmental education, leisure and tourism.

Within this framework, the archaeological excavation, site assessment and site management should take advantage of competencies from various disciplines, such as meteorology, geology, agronomy, topography, botany, geophysics. For example, past and present climate conditions help to understand the changes and migration of ancient human societies; the hydrological network, the geology and the soil aid in understanding urban development, while past and present vegetation are indicators of dietary habits. Overall, the design and management of an archaeological park with modern criteria should consider the archaeological component within an environmental context, that is the result of the interactions of a wide variety of physical, biotic and cultural factors, leading to a broader and deeper understanding of the archaeological site as a whole.

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### Herbicides

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<td>•</td>
<td>•</td>
<td>Herbaceous: annuals, biennials and some perennials</td>
</tr>
<tr>
<td>Simazine</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: annuals and biennials</td>
</tr>
<tr>
<td>Terbuthylazine</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: annuals and biennials</td>
</tr>
<tr>
<td>Isoxaben</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: annuals and biennials dicotyledons</td>
</tr>
<tr>
<td>Hexazinone</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
<td>Herbaceous, trees and shrubs: annuals, biennials and perennials</td>
</tr>
<tr>
<td>Hexazinone + diuron</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
<td>Herbaceous and shrubs</td>
</tr>
<tr>
<td>TCA</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: Poaceae, annuals, biennials and perennials and other monocotyledons</td>
</tr>
<tr>
<td><strong>Leaves</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,4 D, MCPA</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: annuals and biennials dicotyledons, <em>Equisetum</em>, <em>Pteridium</em> and non-Poaceae monocotyledons</td>
</tr>
<tr>
<td>Picloram, Picloram+2,4 D</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
<td>Trees and shrubs; herbaceous: annuals and biennials dicotyledons</td>
</tr>
<tr>
<td>Tryclopyr</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
<td>Trees (except some conifers) and shrubs; annuals and perennials dicotyledons</td>
</tr>
<tr>
<td>Dalapon</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
<td>Herbaceous: annuals and perennials Poaceae and some monocotyledons (<em>Typha, Juncus</em>)</td>
</tr>
<tr>
<td>Paraquat, Paraquat + Diquat</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: Poaceae and annuals and biennials dicotyledon, and for temporary dessication of perennials.</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: Poaceae, annuals and biennials dicotyledon, monocotyledons non Poaceae (<em>Typha</em>), and Chamaephytes (<em>Rubus</em>)</td>
</tr>
<tr>
<td>Glyphosate+MCPA</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: Poaceae, annuals and biennials dicotyledon, monocotyledons non Poaceae (<em>Typha</em>), and Chamaephytes (<em>Rubus</em>), <em>Equisetaceae</em>, and <em>Pteridium</em>.</td>
</tr>
<tr>
<td>Glufosinate-ammonium</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: annuals and biennials dicotyledons;</td>
</tr>
<tr>
<td>Fosamine-ammonium</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Deciduous trees and shrubs; herbaceous, <em>Phragmites</em>.</td>
</tr>
<tr>
<td><strong>Residual and leaves</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picloram+bromacil</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Trees and shrubs; annuals and perennials herbaceous</td>
</tr>
<tr>
<td>Dalapon+bromacil+duron</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: Poaceae and annuals and biennials dicotyledons</td>
</tr>
<tr>
<td>Glyphosate+simazine</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: Poaceae and annuals and biennials dicotyledons</td>
</tr>
<tr>
<td>Glyphosate+terbuthylazine</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: Poaceae and annuals and biennials dicotyledons</td>
</tr>
<tr>
<td>Glyphosate+oxadiazon</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>Herbaceous: Poaceae and annuals and biennials dicotyledons</td>
</tr>
</tbody>
</table>

* It refers to the period of application.

Table 1 - Main herbicides for archaeological parks, period of application and plant (from Miravalle et al. 2001).
Environmental assessment of an archaeological site for the development of an archaeological park

Fig. 1 - Bagnouls and Gaussen diagram for the site of Tilmen Höyük.

Fig. 2 - Depiction of (a) daily cumulative precipitation and average air temperature, and (b) average daily global solar radiation and relative humidity for the year 2007.
Fig. 3 - Wind speed (a) and wind direction (b) at the site.

Fig. 4 - Different products from remote sensing data: (a) orthophoto for the Tilmen Höyük archaeological site, obtained from Quickbird imagery; (b) colour composite ASTER image depicted on SRTM digital terrain model of the region; (c) multitemporal analysis about vegetation index change for an area of about 20 x 20 km² around the site, from Landsat data.
Fig. 5 - 1 m contour line map of Tilmen Höyük with specification of the points where soil samples were collected.

Fig. 6 - Ground Penetrating Radar transect to identify the depth of the groundwater at the transect corresponding to the main gate of the ancient city (K-6 in the archaeological map, cf. Pl. XIII: 1). The time on the Y-axis indicated by the black horizontal line, corresponds to a depth of 130 cm ca, indicating the depth of the water table.