sustainability

MDPI

Article

Vegetation Cover and Tumuli's Shape as Affecting Factors of Microclimate and Biodeterioration Risk for the Conservation of Etruscan Tombs (Tarquinia, Italy)

Giulia Caneva [1,*], Simone Langone [1], Flavia Bartoli [1], Adele Cecchini [2] and Carlo Meneghini [1]

[1] Department of Sciences, University Roma Tre, Viale Marconi 446, 00146 Rome, Italy; simone.langone@gmail.com (S.L.); flavia.bartoli@uniroma3.it (F.B.); carlo.meneghini@uniroma3.it (C.M.)
[2] Cultural Association "Amici delle Tombe dipinte di Tarquinia", Via della Salute 8-12, 01016 Tarquinia, Italy; cecchiniadele@gmail.com
* Correspondence: giulia.caneva@uniroma3.it; Tel.: +39-065-733-6374; Fax: +39-065-733-6321

check for updates

Citation: Caneva, G.; Langone, S.; Bartoli, F.; Cecchini, A.; Meneghini, C. Vegetation Cover and Tumuli's Shape as Affecting Factors of Microclimate and Biodeterioration Risk for the Conservation of Etruscan Tombs (Tarquinia, Italy). *Sustainability* **2021**, *13*, 3393. https://doi.org/10.3390/su13063393

Academic Editor: Bernhard Huchzermeyer

Received: 5 February 2021
Accepted: 16 March 2021
Published: 19 March 2021

Abstract: The conservation of underground tombs is affected by several physical-chemical and biological factors, which could be reduced by insulating systems able to maintain the microclimatic stability also decreasing the biodeterioration risk. In Mediterranean areas, wild ephemeral plants, which reduce their cover during the hot season, seem unsuitable for reducing summer overheating. In this study, we wish to assess the influence of vegetation cover and of overlaying soil, after the establishment of an evergreen turf of a cultivar of *Cynodon dactylon*, on two tombs in the Etruscan Necropolis of Monterozzi, covered by linear-shaped tumuli. Therefore, we evaluated for 10 months the thermo-hygrometric values of these tombs, together with two tombs as controls. We also evaluated the different tumuli's morphologies and the related received solar radiation. Results confirmed that late summer and early autumn as critical microclimatic periods for the risk factors of hypogeal paintings when peaks of superficial temperature occur. A positive influence of vegetation cover on maintaining constant humidity and internal temperatures was detected, but the mounds orientation, as well as soil depth, seems to have a relevant role. Considering the naturalistic features of the area and the related cultural ecosystem services, a careful selection of wild plants is suggested.

Keywords: archaeological parks; biodeterioration prevention; cultural ecosystem services; hypogea microclimate; hypogea conservation; Monterozzi Necropolis; plant cover effects; UNESCO site; wall paintings conservation

1. Introduction

Underground (hypogeal) monuments, such as tombs, catacombs, caves, and sepulchers, are often enriched with wall paintings and stuccoes, which can be affected by several physical-chemical and biological deteriorative factors [1–6]. Considering their placements, their environmental conditions are characterized by high water content of the surfaces and rocks, whereas ventilation, lighting conditions, and temperatures are usually relatively low [7,8].

Humidity and temperatures (T) are the most important factors affecting both physic-chemical and biological deterioration [9–12]. In particular, the associated high values of water content and low temperatures give rise to a high level of relative humidity (RH > 70% and often greater than 90%), which increases in the case of the presence of visitors [13–15]. At high RH levels, condensation can occur, even if a small decrease of the superficial temperature is reached. When percolation also occurs, pigments of mural paintings are washed away from the walls, and chemical lithic effects seriously weather the rocks and mortars [16,17]. Moreover, the high water content creates a suitable environment for bacteria, fungi, and algae, and for roots penetration of plants, responsible for hypogea's biodeterioration [11,18–21]. Furthermore, lighting systems can favor the growth of cyanobacteria and algae [18,22,23], whereas low values of lighting combined with the low ventilation explain the lichens' absence [9].

Hypogea are not isolated systems, and they are susceptible to heat, water, and salts coming from the outside, which can give rise to different weathering processes. For instance, fluctuations of T and RH cause expansion and shrinkage of the materials, which can lead to fragmentation, cracking, and detachment of mural paintings [2,10,11]. In addition, salt crystallization, which can take place on the surface of a wall painting (efflorescence) or beneath it (sub-florescence), leads to surface blooms, and the associated volumetric expansion also gives rise to cracking and detachments of painted layers [1,16,24]. When temperatures increase in the hottest season, a higher risk for biological colonization has been detected, as observed in several sites, such as in ancient Korean tombs [6,25–28]. In fact, for such tombs, three levels of risk for colonization of microorganisms were established, using a scale that follows increasing temperature values [29,30].

Therefore, accurate monitoring of humidity and temperatures is needed to maintain the maximum stability of internal microclimatic conditions in order to avoid the warming that follows the hottest season. This topic has great relevance in particular in the case of fragile environments, such as the hypogeal Etruscan tombs of the Monterozzi area in Tarquinia, which, together with Cerveteri tombs, are part of the UNESCO World Heritage List (WHL) since 2004 [6]. Here, different biodeterioration phenomena are recurrently detected, due to the growth of different bacterial and fungal strains, as well as to root development [31–33], and for such reasons, we selected the site within an international bilateral project (Italy and South-Korea) focused on the conservation of hypogea and their protection against biodeterioration processes [6,34,35].

The practices of building hypogeal tombs and decorating them with mural paintings developed in several Etruscan cities, in a wide region of Etruria, during a period from the 7th to the 3rd century B.C. Their painted tombs have an extraordinary cultural and artistic relevance because they reflect the life, the funeral rites, and the concept of the afterlife of the Etruscans aristocracy [36,37]. In this necropolis, the sepulchral chambers often lie at a variable depth from the surface (from 2 m to 8 m), under variable soil and bedrock types, which have been excavated to obtain them. The original tumuli, which covered the tombs, were often dismantled and only partially rebuilt [38]. The building of mounds as burial marks, a sign that appears from a long distance, has a long tradition, which can be dated even from the last millennium B.C. in the area of the ancient Thracia, Illyria, and Greece, and similar buildings can be found all over the world [39].

These monumental tombs could, however, have a protective reason for the sepulchral chambers. The effects of tumuli on the stability of microclimate were investigated for three Macedonian tombs, showing that the tumulus protects the tomb against the deterioration processes, maintaining the stability of the hydrothermal values thanks to the soil layers [39]. Moreover, the vegetation cover, as a waterproof and insulating system, seems to have a role in the regulation and maintenance of the microclimatic conditions [40]. As a waterproof system, vegetation absorbs part of the rainwater, which is partly retained by the soil layers, contributing to keeping moisture at a suitable level and avoiding percolation [40]. As an insulating system, both vegetation and soil layers seem able to absorb and reflect part of the light radiation, reducing the intensity of thermal waves, which spread to the hypogeum, contributing to keeping the temperature at a suitable level [40]. Moreover, during the penetration through the soil, these thermal waves delay their effects on hypogeal environments for some months [2].

Indeed, the vegetation cover often varies during the seasons, following the climatic variations. In Mediterranean areas, which have hot, dry summers, most species are herbaceous ephemeral plants (Therophytes), which die during summer, surviving as seeds [41]. To improve the stabilization of microclimatic parameters through a better insulation during the hottest season, the perennial plants seem more suitable than the ephemeral ones. In particular, perennial herbaceous plants (Hemicryptophytes) [42] seem optimal for this purpose, because they can maintain the cover without creating high risk of root penetration, such as can occur in the case of wooden plants. Therefore, an experimental evergreen turf of a warm-grass *Cynodon dactylon* (L.) Pers. (Bermudagrass, in the American cultivar 'Premier') was previously selected. *Cynodon dactylon,* which has a wide sub-cosmopolitan distribution, is a macro-thermal plant, which can grow in xeric conditions (low water availability in the hottest season). It is widely adapted to a wide climatic range and to trampling, which justifies its use for sports courses [43,44]. A new turf with this American cultivar, which forms a thin and dense perennial cover [45], was installed in August 2017 on two selected tombs of the Necropolis, thanks to the support of the Hidrowatt Society. To set up such new covers, structured herbal rolls were layered on the tumuli after the scraping of natural plants, but without removing roots, seeds or propagules, and without further irrigation after the initial stages (Barbato, unpublished report). The effectiveness of this green solution, such as the protective effects of the tumuli themselves, still needs to be evaluated.

Therefore, we selected the tombs of the Monterozzi Necropolis where the artificial turf was employed, and others having a wild ephemeral cover, to test the influence of the upper vegetation on the microclimatic conditions of the hypogea. Here, we also wish to evaluate the influence of tumuli characteristics on underground temperatures and establish the most critical conditions for the conservation of tombs, as well as for the biodeterioration risk.

2. Materials and Methods

2.1. Study Area

The Monterozzi Necropolis, which covers an area of about 9.40 ha, is one of the most important Etruscan funerary complexes. It is located on a hill near the city of Tarquinia, in northern Latium, about 70 km N-W from Rome, close to the Tyrrhenian sea (Figure 1). This site is included in a protected zone (SCI/SAC-IT6010028- of the European Directive 92/43/CEE "Habitat") for its naturalistic features. The area falls in the Mediterranean macroclimate (in particular with a lower Mesomediterranean thermotype and an upper dry ombrotype) [46]. Meteorological data on temperature, rainfall, and humidity were taken from the public archive database, showing an average annual rainfall of 648.2 mm, with an average monthly value of 55.0 mm, among which July is the driest one (20.7 mm) and November is the wettest one (102.5 mm) (http://www.idrografico.regione.lazio.it/annali/index.htm, accessed on 18 March 2021). In the 2019–2020 studied period, the average temperature was 16.9 °C, whereas the average minimum and maximum temperature values were, respectively, 5 °C and 31 °C. Late December 2019 to early January 2020 is the coldest period (average value of 7.7 °C, with minimum values around 5 °C), and late June to early August corresponds to the hottest period (average value 27 °C, with maximum temperatures around 31 °C).

The geological substrate of the necropolis, dated back to Pliocene, is composed of marls and clays, sometimes with olistostromes, in the northern parts and detritic and organogenic limestones in the southern one [47]. The rock tombs are cut into a very porous (among 30% and 43% of porosity) and brittle yellowish limestone, locally named Macco, which is also influenced by some risks of instabilities and detachments [48,49].

The necropolis consists of more than 6000 hypogeal tombs cut into the rock and covered by soil mounds, spanning a chronological period from the 7th to 2nd century BC, and about 3% of them are painted, comprising the only great evidence of pre-Roman painting in the Mediterranean basin [38]. Paintings, which were made using soil oxide and mineral pigments on rock or plaster, accurately portray Etruscan civilization, its customs, beliefs, and everyday life of its people (Figure 1) [36]. Most of the original tumuli were probably visible during the 19th century when the area was used for animal grazing, and this explains the toponym "Monterozzi" (in local Italian dialect, it means "small hills"). Their dismantlement was linked to the development of agricultural activities, in the search for increasing the cultivable areas. Few tumuli still maintain the original shape, whereas, in most of them, the present morphology is the result of their partial rebuilding. This partial rebuilding was done during the 1980s, using the soil resulting from the tomb excavations, which was accumulated with a linear orientation to cover the sepulchral chambers [38].

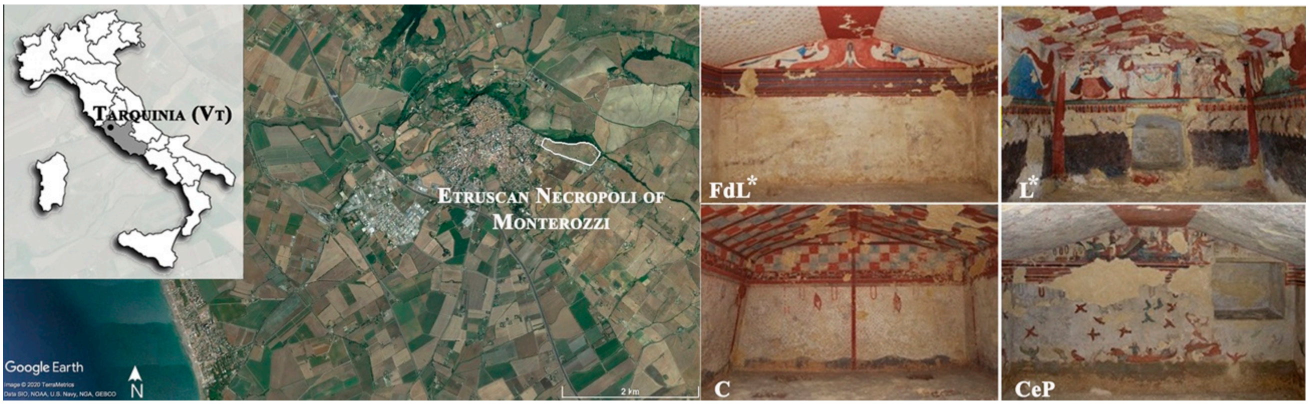

Figure 1. Geographical location of the Monterozzi Necropolis in Tarquinia, in Latium Region, near the Tyrrhenian Sea, and the paintings of the four analyzed tombs Fiore di Loto (FdL*); Leonesse (L*); Cacciatore (C); Caccia e Pesca (CeP) (credits by Simone Langone).

The examined tombs were the two where the experimented turf has been laid on (Fiore di Loto—FdL*—and Leonesse—L*—Tombs) and the other two tombs whose natural cover has been maintained (Cacciatore—C—and Caccia e Pesca—CeP—Tombs). These last ones were selected as controls, considering their proximity and a certain similitude. The tombs are dated between the 6th and 5th centuries BC, and they were discovered between 1873–1874 (CeP and L* Tombs) and 1962 (FdL* and C Tombs). All tombs have one subterranean sepulchral chamber (two in the case of CeP Tomb), accessible through a downhill corridor, called *dromos*. The sepulchral chambers are closed by a thermic door with glass, and visitors can enjoy the pictures, but they are not allowed to enter inside. All the tombs are covered by a not-circular mound, so the sides and the prevailing orientations are also quite different, and the depth of bedrocks varies from 3.27 m (CeP) to 4.33 m (C). A small building, made by a small chamber closed with a metal door, was also settled to protect the entrance to the *dromos* (Figure 2).

2.2. Analysis of Vegetation Changes in Composition and Cover during the Seasons

The analysis of the vegetation growing on the mounds was carried out twice in summer and autumn 2019 to assess the floristic pattern of the different tumuli and their changes in composition and in cover during such seasons, when the overheating of the underground can occur. For such surveys, we followed the Zurich-Montpellier phytosociological method [50], using the coverage index of plants of the Braun-Blanquet scale: + = 0.5%; 1 = 1–5%; 2 = 5–25%; 3 = 25–50%; 4 = 50–75%; 5 = 75–100%. As is usually done, we adopted the average values of such a scale (+ = 0.5%; 1 = 3%; 2 = 15%; 3 = 37.5%; 4 = 62.5%; 5 = 87.5%) to calculate the total cover percentage of each plant, making the sum of them to assess the total cover of the plants in the whole mound. Considering that the vegetation can be stratified according to the different heights of plants, the total value could be higher than 100%. The plants were mostly identified on the field, and the collected samples were later identified in the Herbarium of Roma Tre, following the analytical keys of Pignatti [51]. The nomenclature was finally updated according to Bartolucci et al. [52]. On the field, we also defined the life forms of the plants, considering the usual categories, which are based on their life cycle and the position of buds: Therophytes—T, ephemeral herbs; Hemicryptophytes—H, perennial herbs with buds at soil level; Geophytes—G, perennial herbs with underground storage organs; Chamaephytes—Ch, woody plants with buds at no more than 25 cm above the soil surface; Phanerophytes—P, trees and shrubs with buds over 25 cm above the soil surface [42].

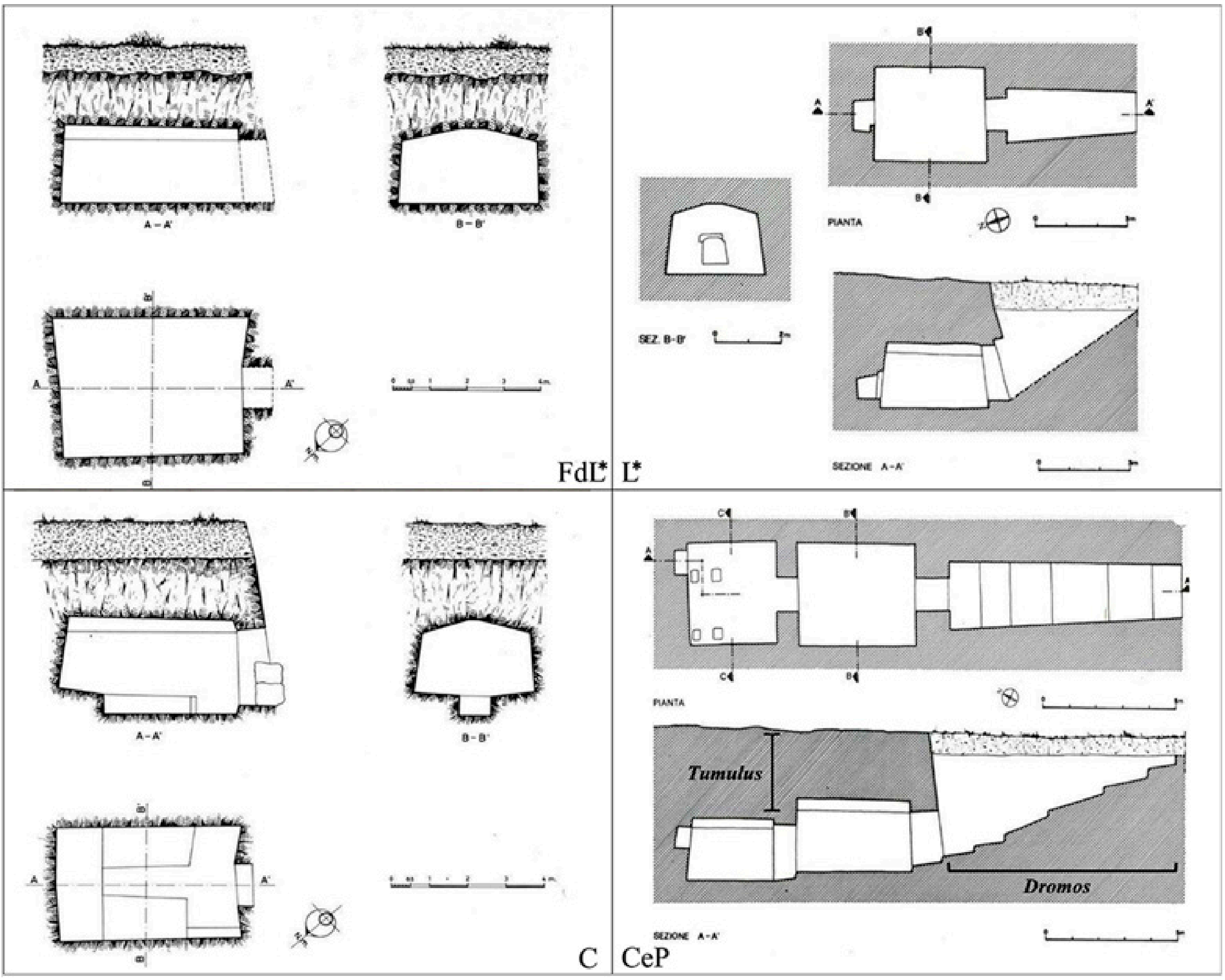

Figure 2. Internal structure of the tombs (tumuli are not enhanced in the drawings Fiore di Loto (FdL*); Leonesse (L*); Cacciatore (C); Caccia e Pesca (CeP) (from Marzullo, 2017).

2.3. Analysis of Tumuli's Shapes and the Solar Radiation Inputs as Related to Microclimatic Influences

Two drone surveys, with APR filming in full HD, were later carried out in autumn 2019 (November) and summer 2020 (July) to characterize the changes in vegetation covers and phenologies (yellowing and death of Therophytes) and for the analysis of the tumuli's shapes. A general model was obtained, using the Autocad software, through the level's curves and the inclination at the soil angle. Then, using the maps of Marzullo [37] (Figure 2) we overlapped the tumuli with the underground structures (Figure 3). From the Marzullo data [37], which contain the dimension of the tombs, we also obtained an approximative evaluation of the volumes of the different sepulchral chambers.

Using the data of tumuli, we also calculated for each tomb the incident solar radiation by the Solarity software (http://www.solaritaly.enea.it/CalcRggmmIncl/Calcola1.php, accessed on 18 March 2021). The calculation was carried out at an assigned location and considering a surface of known geographic orientation. The procedure complies with the requirements of the standard UNI 8477/1 and requires Azimuth and incident at soil angles. Because of the vegetation cover, we calculated the incident solar radiation considering the months with different reflection coefficients, using 0.20 (dry grass) for July, August, and September and 0.26 (green grass) for the remaining months. These data were also used for information on the differential energy input, which can influence the microclimate inside the tombs.

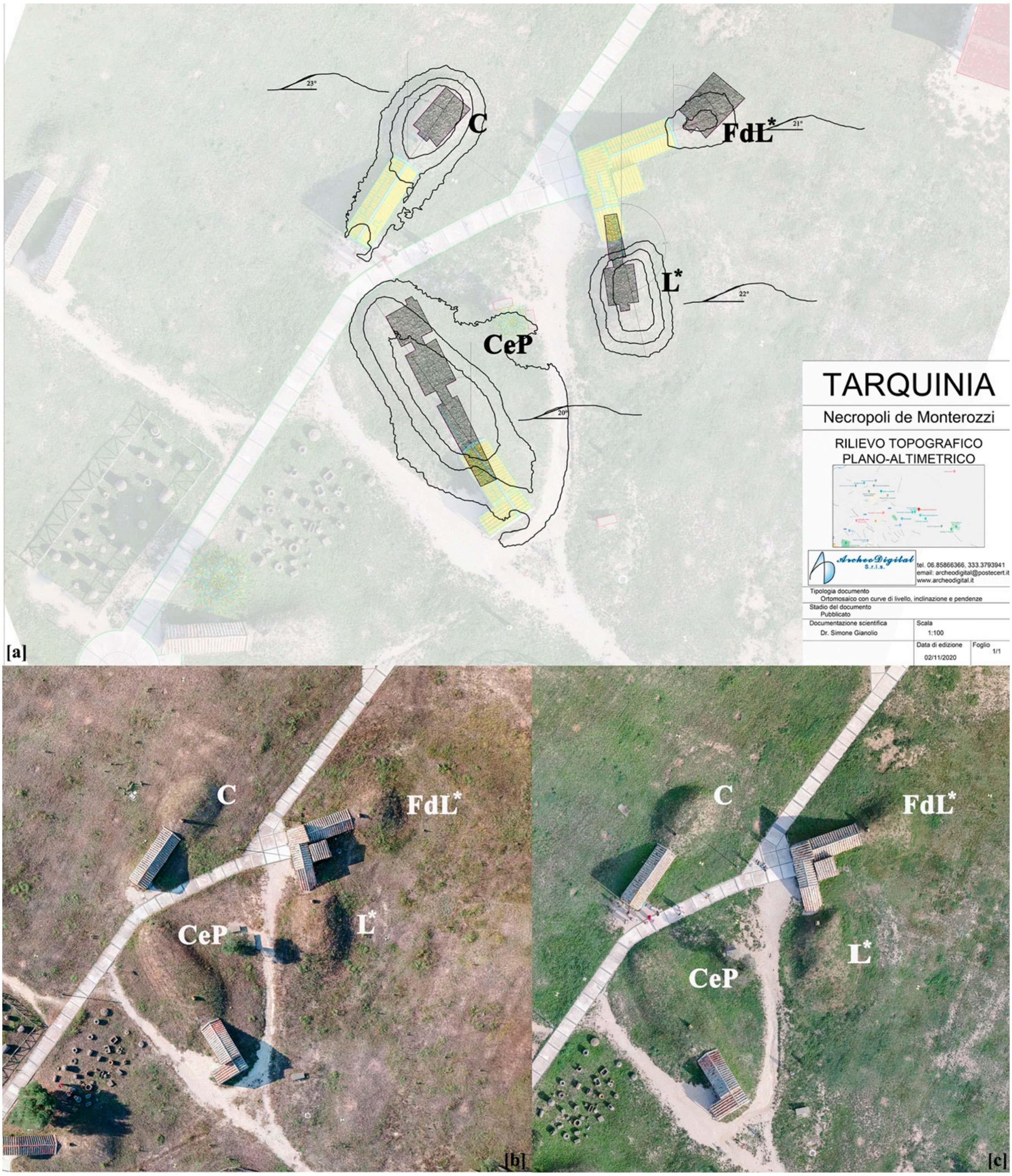

Figure 3. Vegetation cover changes and tumuli shapes, as collected by drone aerial views (by Simone Gianolio, Archeo-Digital® S.r.l.s.) in different seasons: (**a**) topography of the tombs and overlapping of tumuli morphologies, enhanced by level curves and inclination angles; (**b**) vegetation cover in summer; (**c**) vegetation cover in autumn (credits by the authors).

2.4. Collection and Analysis of Microclimatic Data

Data related to the hypogeal environment's microclimate were collected from 29 April 2019 to 21 January 2020, waiting 14 days between each sampling session. Further measurements were not possible due to COVID-19 restrictions. Considering that the relevant seasons for such Mediterranean area are summer, when overheating occurs, and autumn, when the thermal heating is transferred underground, the lack of two months among winter and spring are irrelevant to this study.

Microclimatic data were collected inside the sepulchral chambers behind closed doors through two devices: Flash, an infrared-thermometer (error ±2.5%) used to measure inner surfaces' temperature right wall (W_{dx}), left wall (W_{sx}), front wall (W_{fr}), vault (V), and floor (F) 1 m from them. A thermo-hygrometer (Hygrometer PCE-555) was used to measure the air relative humidity RH (error ±2.5%) and the dew point at the center of the chamber, and the air temperature in the *dromos*, just outside the door of the tomb (*Air*). In the case of the two-room CeP Tomb, air RH and inner surface temperatures (V, F, W_{dx}, W_{sx}) were measured inside the first room, only the front wall's temperature (W_{fr}) was measured in the second one. An example of data set is presented in Figure 4.

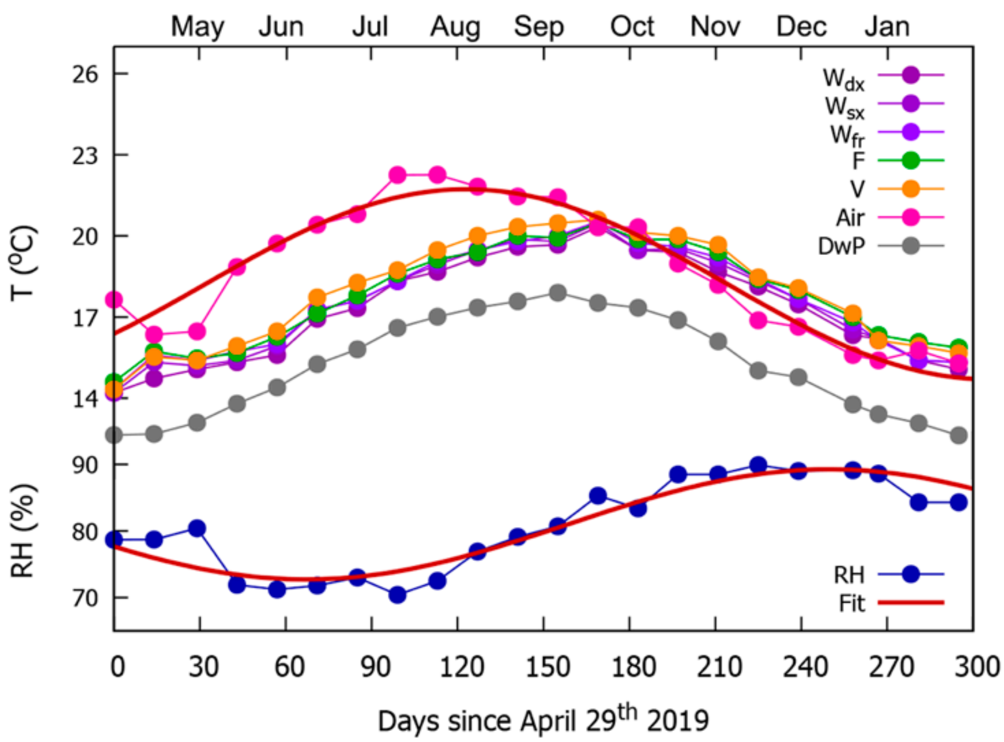

Figure 4. Example of microclimate data (line-points) measured in the FdL* tomb: the air temperature just outside the entrance (Air) and the temperatures measured on the right (W_{dx}), left (W_{sx}) and front (W_{fr}) wall, on the floor (F), on the vault (V) and the dew point temperature (DwP). Below are reported the relative humidity (RH) data. The best fit to Air and RH data is shown for sake of example.

To quantify the microclimate behavior in the tombs, the data were fitted to a sinusoidal function with 365 days:

$$f(t) = T_{ave} + \frac{\Delta T}{2} \sin\left(\frac{2\pi}{365}(t - t_o)\right) \quad (1)$$

in which T_{ave} (°C) is the average temperature in the measurement period and ΔT (°C) is the maximum temperature difference along the seasonal cycle. Equation (1) reaches a maximum $t = \frac{365}{4} + t_o$ (days) after the start of measurements (29 April 2019). The same model is used to fit the meteorological data. For humidity data, RH_{ave} is the average relative humidity and $\Delta(RH)$ the amplitude of RH variation along the seasonal cycle (Figure 4). In each tomb, the wall temperatures (front, right, left walls) had very similar values, with no significant differences, and therefore, they were averaged in a single dataset labeled as W in the relevant figures and discussion.

3. Results

3.1. Changes in Vegetation Cover during the Analysed Seasons

In the archaeological site, the vegetation is mainly constituted of herbaceous species, with just a few trees and shrubs, usually growing far from the tombs. In the limited areas of the four tumuli, a total of 39 different species (and 17 Families) was detected. This floristic pattern mainly belongs to the *Thero-Brachypodietea* and *Festuco-Brometea* phytosociological classes, which describe ephemeral and perennial grasses in the Mediterranean areas [53]. Most plants also show and Euromediterranean chorotype, followed by those with wide distribution or Stenomediterranean ones (Table 1). Indeed, a higher number of plant species was detected in the archaeological site, and the highest number was detectable during Spring (unpublished data). Since most of the ephemeral herbaceous species (Therophytes) die during Summer, in this season, the plants' cover is reduced and mainly constituted by perennial herbaceous plants (Hemicryptophytes, 25 species, and Geophytes, 2 species) and in limited parts by plants of other life forms (Chamaephytes, 2 species, and Therophytes 10 species). The collected plants often had relevant changes in their presence and cover during the seasons. In autumn, when the annual plants grow back, an increase in both the number of species and the plant cover was detected (Tables 1 and 2). On the tumuli covered by the artificial cover of *Cynodon dactylon*, a not negligible regrowth of spontaneous species was detected. This fact proves the ability of both seeds and vegetative parts, which remained underground, to recolonize the natural spaces. *C. dactylon* showed its maximum cover in Summer and a reduction of it in Autumn.

Table 1. Variations of plant composition and cover (in Braun-Blanquet scale) from summer to autumn on the tumuli of the four analyzed tombs. Acronyms: FdL* = Fiore di Loto; L* = Leonesse; C = Cacciatore; CeP = Caccia e Pesca. Ch suffr: Chamaephytes suffruticose; G rhiz: Geophytes rhizomatose; H bienn: Hemicryptophyte biennial; H caesp: Hemicryptophyte caespitose; H ros: Hemicryptophyte rosulate; H scap: Hemicryptophyte scapose; T caesp: Therophytes caespitose; T scap: Therophytes scapose. Euri-medit: EuriMediterranean, Steno-medit: Stenomediterranean; Eurasiat: Euriasiatic; Circumbor: Circumboreal; Endem: Endemic; Wide distr: wide distribution; Europ: European; Euro-Cauc: Eurocaucasian; Silv-cult: agronomic origin; Submedit: Submediterranean; Paleotemp: Paleotemperate; Subcosmop: Subcosmopolite; Eurosiber: Eurosiberian.

Family	Chorotype	Species	Life Form	Cover Values Summer				Cover Values Autumn			
				FdL*	L*	C	CeP	FdL*	L*	C	CeP
Lamiaceae	Steno-medit.	*Clinopodium nepeta* (L.) Kuntze	Ch suffr		+				1		
Lamiaceae	Euri-Medit.	*Teucrium chamaedrys* L.	Ch suffr								+
Asphodelaceae	Steno-medit.	*Asphodelus ramosus* L.	G rhiz					1	1		
Poaceae	Silv-cult	*Cynodon dactylon* (L.) Pers. var. *Premier*	G rhiz	5	5			4	4		
Asteraceae	Submedit	*Crepis vesicaria* L.	H bienn	1				1			
Boraginaceae	Euri-medit.	*Echium plantagineum* L.	H bienn				+				+
Apiaceae	Steno-medit.	*Seseli tortuosum* L.	H bienn	+	+	+	+	1	1	1	1
Caprifoliaceae	Steno-medit.	*Sixalix atropurpurea* (L.) Greuter & Burdet	H bienn								+

Table 1. *Cont.*

Family	Chorotype	Species	Life Form	Cover Values Summer				Cover Values Autumn			
				FdL*	L*	C	CeP	FdL*	L*	C	CeP
Scrophulariaceae	Euri-medit.	*Verbascum sinuatum* L.	H bienn			1	+			1	+
Poaceae	Euroasiat.	*Dactylis glomerata* L.	H caesp				+				2
Asteraceae	Euro-Cauc.	*Bellis perennis* L.	H ros								+
Asteraceae	Steno-medit.	*Hyoseris radiata* L.	H ros	+	+	+	+	1	1	2	2
Plantaginaceae	Euroasiat.	*Plantago lanceolata* L.	H ros	+	+			1	1	+	
Asteraceae	Steno-medit.	*Centaurea aspera* L.	H scap	+	+			+	1		+
Convolvulaceae	Euri-medit.	*Convolvulus cantabrica* L.	H scap	1	2	+	+	+	1	1	1
Asteraceae	Euri-medit.	*Crepis bursifolia* L.	H scap					+			
Brassicaceae	Euri-medit.	*Diplotaxis tenuifolia* (L.) DC.	H scap	+	+	+		1	1	1	
Apiaceae	Euri-medit.	*Ferula communis* L.	H scap	1	1	1	1	1	1		1
Apiaceae	Steno-medit.	*Foeniculum vulgare* Mill.	H scap	2	1	1	5	1	1	+	2
Lamiaceae	Eurasiat.	*Lamium maculatum* L.	H scap					+	+		
Plantaginaceae	Endem.	*Linaria purpurea* (L.) Mill.	H scap	+				+			
Malvaceae	Wide distr.	*Malva sylvestris* L.	H scap		+		1	+	2	+	2
Fabaceae	Subcosmop.	*Medicago sativa* L.	H scap		1						
Asteraceae	Eurosiber.	*Picris hieracioides* L.	H scap	1		1				1	
Asteraceae	Steno-medit.	*Reichardia picroides* (L.) Roth	H scap	+	+	+	+	2	2	2	3
Polygonaceae	Euroasiat.	*Rumex acetosa* L.	H scap	+	+			2	+		+
Lamiaceae	Euri-medit.	*Salvia verbenaca* L.	H scap	+	+	1	1	1	1	3	3
Caryophyllaceae	Euroasiat.	*Silene vulgaris* (Moench) Garcke	H scap	1	+	+		2	2	1	+
Asteraceae	Euri-medit.	*Urospermum dalechampii* (L.) F.W. Schmidt	H scap						+		+
Geraniaceae	Subcosmop.	*Erodium cicutarium* (L.) L'Hér.	T caesp								+
Asteraceae	Steno-medit.	*Anthemis arvensis* L.	T scap							1	
Poaceae	Euroasit.	*Avena fatua* L.	T scap		2						
Asteraceae	Euri-medit.	*Calendula arvensis* (Vaill.) L.	T scap					2	3	2	2
Asteraceae	C-Europ.	*Crepis capillaris* (L.) Wallr.	T scap					1		+	
Poaceae	Euri-medit-Turan.	*Dasypyrum villosum* (L.) P. Candargy	T scap	+		+	+	1	1	1	2
Asteraceae	Subcosmop.	*Erigeron canadensis* L.	T scap							1	

Table 1. *Cont.*

Family	Chorotype	Species	Life Form	Cover Values Summer				Cover Values Autumn			
				FdL*	L*	C	CeP	FdL*	L*	C	CeP
Euphorbiaceae	Subcosmop.	*Euphorbia helioscopia* L.	T scap			+		1			
Geraniaceae	Subcosmop.	*Geranium molle* L.	T scap					1			
Asteraceae	Steno-medit.	*Sonchus tenerrimus* L.	T scap								1
Total number				17	16	13	12	24	20	17	22

Table 2. Changes in plant cover (%) from summer to autumn on the tumuli of the four analyzed tombs. (Values in brackets represent the total cover on the surface without considering the plant stratification).

	FdL*	L*	C	CeP
Summer	123% (100)	132% (100)	19% (20)	101% (65)
Autumn	165% (100)	183% (100)	112% (70)	182% (100)
Difference: D = A − S	42%	50.5%	92.5%	81.5%
Ratio : $R = \frac{S}{A}$	0.74	0.72	0.17	0.55
Relative change $\epsilon = \frac{Autumn - Summer}{Autumn}$	0.25	0.28	0.83	0.44

In particular, significantly lower values of plant richness (from 12–13 species to 22–17 species) were observed in summer compared to autumn in tombs with natural covers. The highest number of species (from 16–17 species to 20–24 species) was observed in summer in comparison with Autumn in tombs with the turf of *Cynodon dactylon* 'Premier' (Table 1).

More important, significantly lower values of plant cover were observed in summer than in autumn for the tombs with the turf of *Cynodon dactylon* (FdL* and L*) (Tables 1 and 2). These values of plant cover increase from 2 to 5 times in the case of the tombs with natural covers (CeP and C, relative values in Table 2). The collected data also show that even the tombs covered by the *Cynodon dactylon* mat do not reach a total cover of the surfaces (values in brackets), despite a coverage value exceeding 100%, due to the underlined stratification of herbaceous plants with different heights. The FdL* and L* Tombs present a lower difference in the plant cover compared to the C and CeP Tombs, where we observe high changes between summer and autumn (ϵ in Table 2), which can be estimated as 93%.

These changes in cover, as well as in the phenology of the plants, are stressed by the aerial photographs. Whereas Therophytes die, Hemicryptophytes (and *Cynodon dactlylon* too) show yellowing and a reduction of their life activities during summer (Figure 3). Few of them, such as *Foeniculum vulgare*, *Ferula communis*, *Convolvulus cantabrica*, *Salvia verbenaca Picris hieracioides*, and *Clematis cirrhosa*, which were found in other parts of the site, remain fully active during summer.

3.2. *Seasonal Trends of Microclimatic Data and Related Risks for Weathering and Biodeterioration Phenomena*

The trends of microclimatic data are presented in Figure 4, with the best fits to air temperature and RH data obtained using the Equation (1) and with the FdL* Tomb as example. In fact, the behavior of the microclimatic data is visually very similar in all the tombs, and, to quantitatively compare the microclimatic data of the different tombs, the best-fit parameters are presented in Figure 5a–c.

The microclimatic data depict an evident swinging trend related to the seasonal periodicity (Figure 4), and it is evident that the temperature variation measured in the *dromos* is anticipated compared to those measured inside the sepulchral chambers of the tombs, because it is not completely isolated from the outside. The interiors of the tombs are isolated from the *dromos* by a tight door; therefore, they are less influenced by external temperature variations.

In the investigated period, the average external temperature (meteorological data) was 16.9 °C, varying by ±9.5 °C between the maximum average temperature in the period late June to early August (60–110 days after 29th April) and the minimum temperature in late December 2019 to early January 2020.

The parameters presented in Figure 5a show that the average sir temperature (T_{ave}) and the amplitude of temperature variation along the seasonal cycle (ΔT) in the *dromos* were systematically higher than those measured on the tombs' surfaces. The average air temperature here varied between 18.2 ± 1 °C (FdL*) and 19.4 ± 2 °C (CeP). In all the tombs, the T_{ave} of the surfaces ranged from 17 °C to 18 °C. The average seasonal temperature variation ΔT of the surfaces was around 6–7 °C for FdL* and L* tombs and significantly lower, around 4 °C, for the CeP. The ΔT of the *dromos* Air is also noticeably reduced in the CeP Tomb compared to the other tombs. This could be due to the longer and deeper tunnel at the entrance of the *dromos* of this tomb, which stabilizes the values. Furthermore, we notice that in all the tombs, the ΔT of the floor (F) is systematically the lowest one and that of the vault (V) the highest, whereas the walls (W) have intermediate values. The T_{ave} and ΔT values obtained fitting the dew point temperature data appear very similar without significant differences in all the tombs.

The temperature oscillations in both conditions followed the external changes with a delay: the air temperature in each *dromos* reached the maximum in late August to early September (around 120 days after the 29th April), about one month after the external meteorological temperatures. Inside the tombs, the temperatures reached the maximum in early/late October 2019, with a delay of more than one month after the *dromos*' behavior. Such a trend is likely due to the *dromos* not being completely isolated from the outside, whereas the interiors of the tombs are isolated by tight doors. Such a delay between *dromos* and the interior of the tombs was the least for the L* and FdL* Tombs (30–40 days) and the greatest (50–60 days) for the C and CeP Tombs.

The relative humidity (RH) data were fitted to Equation (1), and the best-fit parameters are reported in Figure 5c. The RH_{ave} was the highest for FdL* Tomb (82%) and the most constant one, presenting the lowest variability $\Delta(RH) \approx 6\%$, in the measured period. The RH_{ave} decreased to around 78% for the CeP Tomb, which, together with the C Tombs, had the greatest humidity variation $\Delta(RH) \approx 10\%$, along the measured period. The minimum RH was found between late June and early July in all the tombs, except for CeP, which the minimum RH around the 20th of July.

Considering the risks for the hypogeal conservation, we can observe that in every hypogeum, the temperature variation is attenuated and delayed compared to the outside. In addition, the tight doors protect the tomb interiors.

The microclimatic data in FdL* and L* Tombs behave noticeably differently from C and CeP Tombs: ΔT of vaults and walls is greater for FdL* and L*, which also have the least delay concerning external temperature variation, suggesting a reduced thermal screening. As shown by the humidity data, also in this case the FdL* and L* humidity of vaults and walls is systematically higher with less variability than C and CeP Tombs.

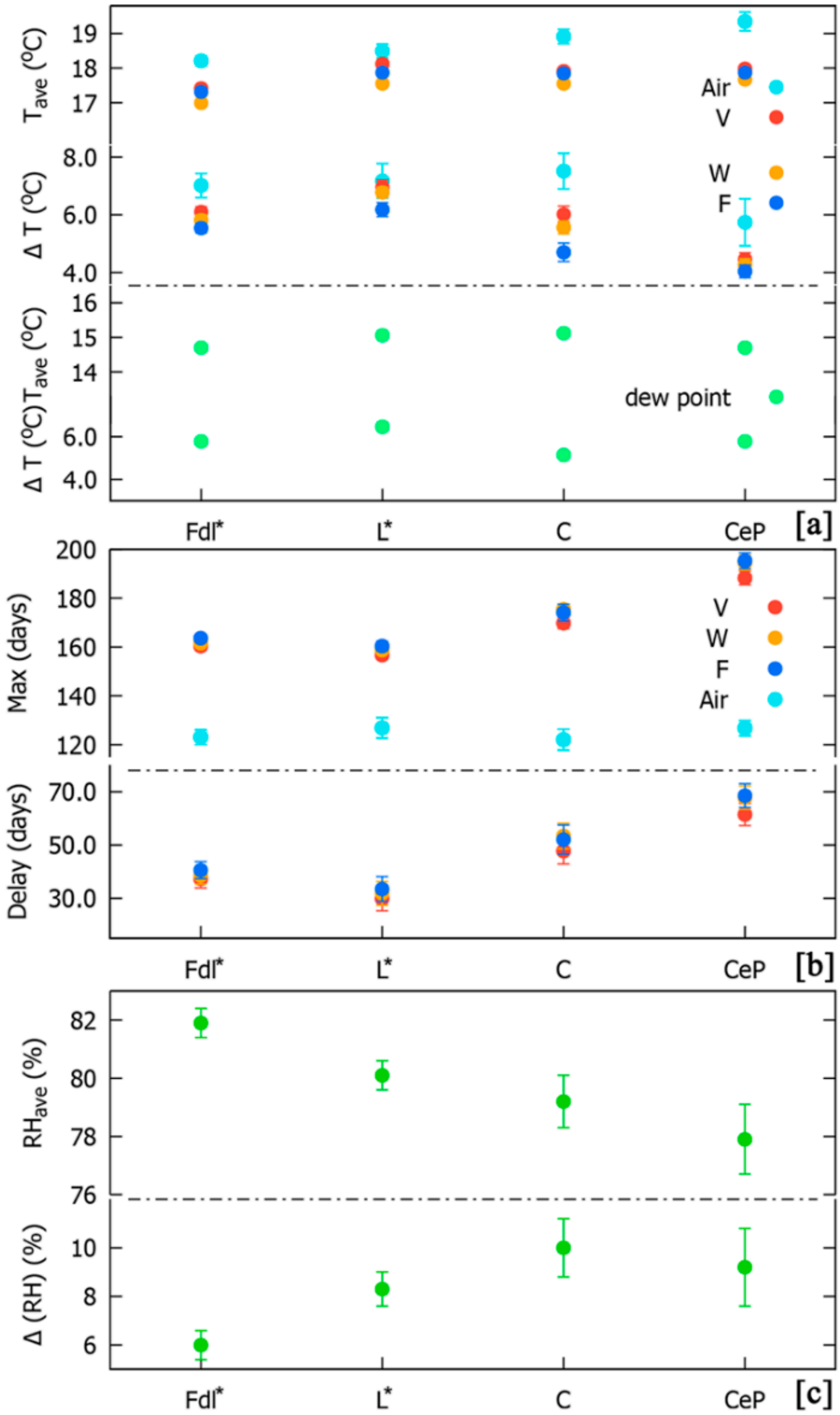

Figure 5. Best-fit parameters obtained from the analysis of the temperatures measured in the tombs. (**a**) In the top plots, the average temperature (T_{ave}) and seasonal temperature variation amplitude (ΔT) are reported for the external area of dromos (Air), the vaults (V), the walls (W) and the floors (F) of the four tombs. In the lower plots, T_{ave} and ΔT are reported for the dew point. Not shown error bars are smaller than the symbol sizes; (**b**) days after 29th April corresponding to the maximum temperature in the fit of air, vault (V), walls (W), and floor (F) data set for the four tombs. The delay (days) between the maximum temperature of air data and internal surfaces (V, W, and F) is presented in the lower panel for sake of clarity; (**c**) average relative humidity (RH_{ave}) and relative humidity variation $\Delta(RH)$ as obtained fitting the data using Equation (1). Acronyms: Fiore di Loto (FdL*); Leonesse (L*); Cacciatore (C); Caccia e Pesca (CeP).

3.3. Relationships among External Factors and Underground Microclimatic Data

The drone survey allowed us to precisely describe the shape, orientation and overlapping of the tumuli with the underground tombs. Tumuli create a partial covering of the sepulchral chambers (Figure 3a). Considering the different orientations of the tumuli and their shapes, we calculated the different incident solar radiations received by the tumuli reported in Table 3. This Table also gives information on the heights and the volumes of the internal sepulchral chambers, which were different in size, but relatively comparable. They respectively varied between 2.1 m and 2.6 m in height and from 24 m^3 to 40.86 m^3 in volume (for the CeP tomb, two chambers were present for a whole of 62.36 m^3).

Such data show that two tumuli (C and FdL*) receive the highest solar radiation, whereas one tumulus (L*) receives lower radiation. Such a difference is the highest during winter and autumn, but, even though it is lower during summer (especially from June to August), this value is particularly relevant for the overheating that occurs above all during this season. The variation of the total values is not negligible since it can be about 25% (145:195).

Table 3. Tumuli characteristics and monthly values of incident solar radiation (MJ/mq) received by the four tumuli (FdL* = Fiore di Loto; L* = Leonesse; C = Cacciatore; CeP = Caccia e Pesca). The yellow lines represent the summer months.

Tumuli		FdL*	L*	C	CeP
Height (m) of sepulchral chambers		2.15	2.1	2.61	2.5 (I r_{oom}) 2.1 (II $_{room}$)
Volumes (m^3) of sepulchral chambers		40.86	23.94	38.35	38.4 (I r_{oom}) 23.9 (II_{room})
Months	January	8.44	3.55	9.94	4.28
	February	10.98	6.12	12.28	6.97
	March	15.42	10.54	16.52	11.42
	April	18.4	15.19	18.9	15.77
	May	21.72	20.02	21.69	20.35
	June	23.44	22.7	23.09	22.9
	July	23.26	22.06	23.04	22.34
	August	20.45	17.77	20.83	18.26
	September	16.39	12.37	17.39	13.1
	October	12.43	7.66	13.61	8.5
	November	8.79	4.27	10.1	5
	December	6.6	2.92	7.78	3.44
	Annual	186.32	145.17	195.17	152.33

For the analysed underground tombs, Figure 6 shows the co-occurring changes of vegetation cover during the two relevant seasons and the incident solar radiations received by their covering tumuli, as related to their potential effects on ΔT and their delays. Interestingly, analogies among the variation of ΔT and the delay can be observed for C and CeP Tombs, which also show the lowest plant cover: indeed, these tombs show a lower ΔT and the longest delay.

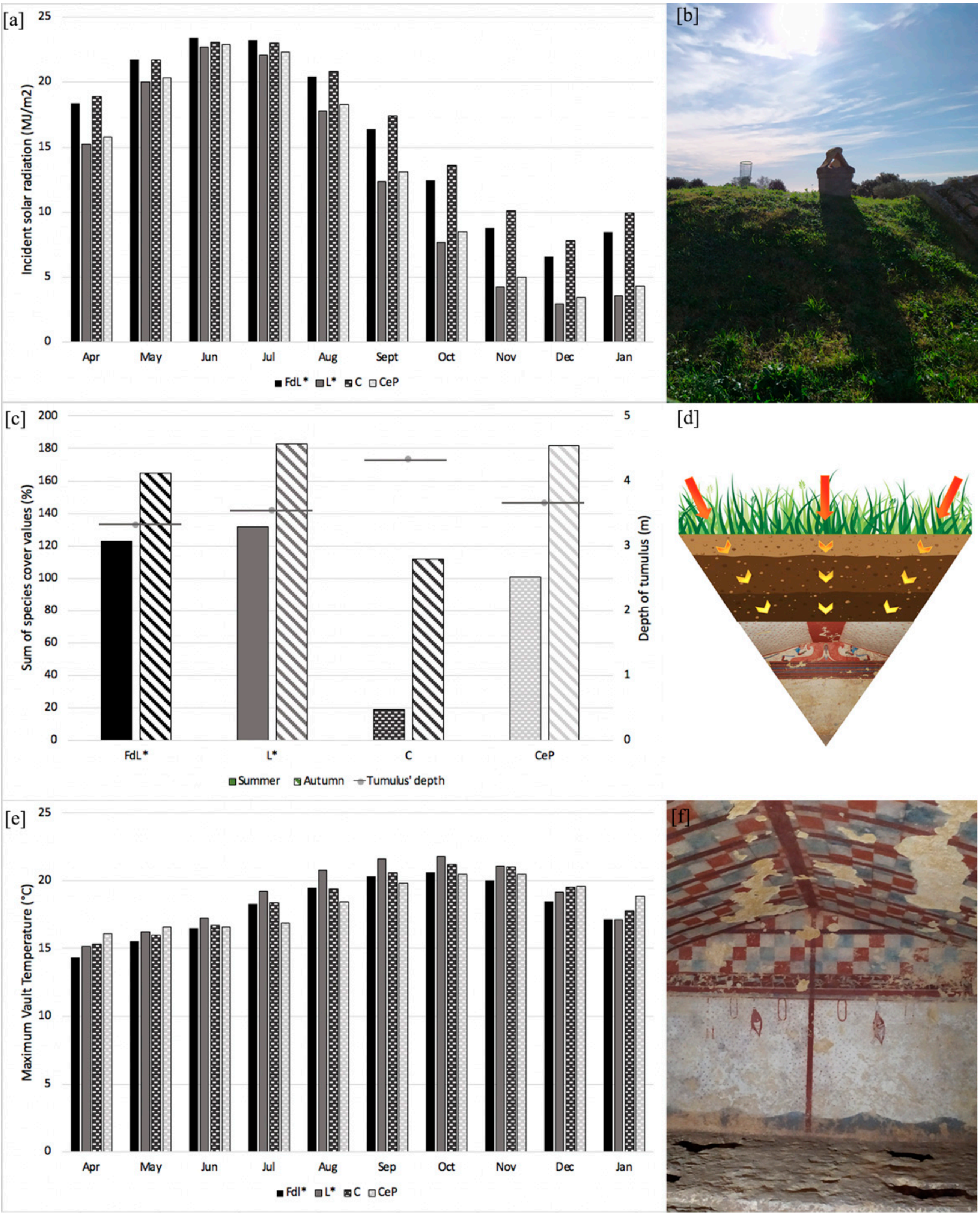

Figure 6. Relation among outdoor conditions with indoor microclimate of tested tombs. (**a**) Solar incident radiation graph; (**b**) photos of a sunny day on the tumulus; (**c**) seasonal cover vegetation changes related to the depth of tumuli; (**d**) graphic representation of overheating of tumulus; (**e**) Maximum indoor temperature of the vaults; (**f**) photos of the vaults of Cacciatore tomb. Acronyms: Fiore di Loto (FdL*); Leonesse (L*); Cacciatore (C); Caccia e Pesca (CeP).

4. Discussion

The different vegetation cover and depths of bedrocks, as well as the tumuli shapes and aspects, were shown to be the relevant influencing factors for the microclimatic conditions of the underground tombs. In particular, the role of the upper vegetation coverage as influencing factors of the microclimatic conditions, as suggested by previous authors [40], seems not negligible, but at the moment, we have insufficient data to quantify its weight in such a complex system. The plant cover has a clear seasonality in the Mediterranean area, and the perennial grasses can contribute to minimizing the thermal overheating.

The selection of the best plant cover needs, however, a careful consideration of other parameters. First, this includes the potential role of the roots in penetrating underground and creating damage through physic-chemical interactions with rocks and mural paintings, as analysed in further papers (e.g., Isola et al., 2021b). Such data also show that among the 39 detected species on these tumuli, eight were able to penetrate underground. Plants also can give rise to a change in microbial biodeteriogenic communities and favor water penetration, as proven by several authors [6,54,55]. Furthermore, considering that the area is included in a naturalistic protected area of the European Habitat Directive, considering naturalistic parameters in selecting plants is required. The Mediterranean grassland should be protected if no negative interactions of some plants (e.g., root penetration underground) with the archeological structures are detectable. From this point of view, the selection of the American variety of the warm-grass cultivar of *Cynodon dactylon* is not the best fit, and it would be preferable to check the suitability of other wild perennial grasses. In fact, in order to contribute to the management plan of the site, the best selection of plants is needed, which are suitable as cover for the tombs. This selection should consider more carefully the suitability for performing the projected functions (here the potential of covering in summer, such as perennial herbaceous plants, and in particular Hemicryptophytes), their naturality and representativeness of wild communities, the absence of risk for roots penetration underground, and further naturalistic parameters [56–59]. As a preliminary list, some wild perennial herbaceous species already present in the site, could be considered, such as *Convolvulus cantabrica, Salvia verbenaca, Picris hieracioides,* and *Clematis cirrhosa*, which were not in the list of the root penetrating plants [35]. A careful evaluation of plants as elements for cultural ecosystem services suitable for the preservation of archaeological artifacts would be welcomed. Indeed, the use of natural elements for protecting cultural heritage was previously suggested, and especially the need of safeguarding both natural and cultural values [9,58,59]. As for urban community gardening, where the "cultural values" of plants were suggested as an additional ecosystem service [60], in case of archaeological areas, natural plants could have a role both in protecting and enhancing the value of the sites.

In fact, when considering the conservation problems of the tombs, this artificial turf, compared to a natural vegetation cover, seems to have some positive effects, but not enough to finally encourage it as a solution. For example, a direct correlation between solar irradiation and internal temperatures was not clearly detected, whereas the tombs with the highest plant cover showed the highest humidity with less variability in hygrometric values, but also a larger ΔT and a lesser delay concerning external temperature variation. Whereas constant induced humidity values are positive effects, the low thermal screening, also enhanced by lower thermic inertia, seems to be an effect that needs to be improved through a more efficient plant cover.

Moreover, this analysis showed the influence of the shapes and orientation of the tumuli, as well as of the soil layers and plant cover, for a better protection of the underground tombs, as observed by Kyriakou and Panoskaltsis [39]. South-facing can have a negative effect on additional thermal input, which is transferred underground, giving rise to an increase in internal temperature. In particular, when south-facing exposition occurs, an improvement in the thermal insulation system seems necessary. More importantly, tumuli rebuilding, conserving the roundish original shape and a sufficient wide size, seems necessary, not only for the philological reason in the archaeological site but also because a roundish shape does not create a preferential exposure and because of the need to guarantee a more efficient shelter of the underground. A widening of the comparative analysis of the Etruscan tombs, having a great number of differential influencing parameters, to permit statistical elaborations, is also needed. Further efforts will be done in analyzing all the parameters that influence the thermal transmission underground, such as the depth and size of the hypogea, the length of the *dromos*, and the building that protects the first entrance, combining them with the transmittance of the bedrocks.

When considering the presently most critical conditions for physical-chemical damages, C and CeP tombs were shown to be at the highest risk of developing saline efflorescence and cracks of the pictured layers, due to the variability of thermohydrometric conditions. In this case, the risk due to condensation was shown to be limited.

When considering the biodeterioration risk, humidity, temperatures, lighting, and nutrients all have a relevant role. Indeed, the microflora of the hypogea is influenced by such environmental parameters, with effects due to the selective, competitive, and inhibitory processes among different microorganisms that give rise to different characteristic communities [4,12,34,61–63]. In general, fungi were found to be more resistant to dryness than bacteria [6,64]. The human influences and the opening time of the hypogea also give rise to a higher variability [4,7,65].

Some environmental factors and external influences can be more or less easily controlled and reduced, but other factors cannot reach the risky values, such as the RH, whose critical values start from 60%. Reaching stationary environmental conditions, avoiding external inputs of spores, condense, high lighting, and overheating, are very important in reducing the biological risk.

Avoiding critical values of T has a non-negligible importance for biodeterioration risk. As previously observed for the airborne microflora in other underground historical places [65–67], such as the crypt of the Anagni's Dom (Italy) [25], or the crypt of St. Peter in Perugia (Italy) [26], a high risk for biological colonization originates from overheating, which follows the summer season. When considering data from Korean literature for hypogea conservation, three risk periods for microorganism occurrence were established as follows: (1) Safe: T < 18 °C, (2) Warning: T = 18–22 °C, (3) Risk: T > 22 °C [29,30,68]. If we apply such values to the Etruscan tombs, a safe period occurs from late autumn and winter until spring. Starting from June to July a warning period is detectable, and a risk period from August to September as well, especially when the vegetation cover is very low, and the orientation of the tumuli is south-facing (e.g., C Tomb).

5. Conclusions

The collected data show the complex network of relationships among various parameters affecting the conservation of such a subterranean cultural heritage. A positive influence of vegetation cover in maintaining higher and more constant humidity conditions was detected. Plant covers also influenced internal temperatures, but the mounds' orientation, as well as other constructive features, also seem to have a relevant role. Data confirmed that late summer and early autumn are the most critical microclimatic periods for the hypogeal paintings and biological risks when peaks of superficial T occur. To improve the insulation systems, we suggest a careful rebuilding of tumuli over the tombs, as well as a better selection of wild plants that do not create a risk of roots penetration underground and are suitable for maintaining their covering during summer.

Author Contributions: Conceptualization, G.C., A.C., C.M.; Methodology and Validation, G.C., C.M.; Formal Analysis and Investigation, S.L., F.B., A.C.; Writing, G.C., S.L., C.M. Funding Acquisition, G.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by a grant from the Italian Ministry of Affairs and International Cooperation Program "Research of conservation environment and eco-friendly damage control of cultural heritage Korea and Italy", grant number PGR06686. This work was also supported by the Grant to Department of Science, Roma Tre University (MIUR-323 Italy Departments of Excellence, Article 1, Comma 314–337, Low 232/2016).

Institutional Review Board Statement: This study don't involve animals.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: At this links it is possible find the climatic data and the solar radiation data: http://www.idrografico.regione.lazio.it/annali/index.htm, accessed on 18 March 2021 and http://www.solaritaly.enea.it/CalcRggmmIncl/Calcola1.php, accessed on 18 March 2021.

Acknowledgments: The authors wish to thank the Direzione Regionale Musei Lazio (Daniela De Angelis, Director of the Cerveteri and Tarquinia UNESCO Site) and the Soprintendenza Archeologia Belle Arti e Paesaggio per l'Area Metropolitana di Roma, the Province of Viterbo e l'Etruria Meridionale (Daniele Federico Maras). Many thanks to Simone Gianolio (ArcheoDigital® S.r.l.s.) for the drone surveys. We wish also to thank Sandro Massa (CNR) for inspiring such investigation, and we dedicate this work to his memory, remembering his tireless contribution to the conservation of the Etruscan tombs.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Paribeni, M. *Cause di Deperimento e Metodi di Conservazione Delle Pitture Murali Delle Tombe Sotterranee di Tarquinia*; Rapporto Scientifico C.N.R.—Istituto di Fisica Tecnica di Roma, Edizioni Sistema: Rome, Italy, 1970.
2. Massa, S.; Nichi, D. Conservazione e fruizione: Analisi ambientale sulle tombe dipinte di Tarquinia. In *Etruria Meridionale: Conoscenza, Conservazione, Fruizione, Proceedings of Convegno Viterbo, Italy, 29 November–1 December 1985*; Bettini, C., Colonna, G., Staccioli, R., Eds.; Casa Editrice Quasar: Rome, Italy, 1988; pp. 139–143.
3. Bracci, S.; Cuzman, O.A.; Ignesti, A.; Del Fa, R.M.; Olmi, R.; Pallecchi, P.; Riminesi, P.; Tiano, P. Multidisciplinary approach for the conservation of an Etruscan hypogean monument. *Eur. J. Sci. Theol.* **2013**, *9*, 91–106.
4. Saiz-Jimenez, C. *The Conservation of Subterranean Cultural Heritage*; CRC Press Taylor & Francis Group: London, UK, 2014; ISBN 9781138026940.
5. Chung, Y.J. Conservation environment of Korean mural tombs in the period of the Three Kingdoms. In *Proceedings of the International Conference on Conservation of Stone and Earthen Architectural Heritage, Gongju, Korea, 20–23 May 2014*; Lee, C.H., Kim, J., Kim, R.H., Eds.; Kongju National University: Gongju, Korea, 2014; ISBN 979-11-953029-0-1.
6. Caneva, G.; Isola, D.; Lee, H.J.; Chung, Y.J. Biological Risk for Hypogea: Shared Data from Etruscan Tombs in Italy and Ancient Tombs of the Baekje Dynasty in Republic of Korea. *Appl. Sci.* **2020**, *10*, 6104. [CrossRef]
7. Albertano, P.; Urzì, C.; Caneva, G. Tombs, catacombs, and other hypogean environments. In *Plant Biology for Cultural Heritage: Biodeterioration and Conservation*; Caneva, G., Nugari, M.P., Salvadori, O., Eds.; Getty Con-servation Institute: Los Angeles, LA, USA, 2008; pp. 77–81.
8. Jeong, S.H.; Lee, H.J.; Lee, M.Y.; Chung, Y.J. Conservation Environment for Mural Tomb in Goa-ri, Goryeong. *J. Conserv. Sci.* **2017**, *33*, 189–201. [CrossRef]
9. Caneva, G.; Nugari, M.P.; Salvadori, O. *Plant Biology for Cultural Heritage: Biodeterioration and Conservation*; Getty Publications: Los Angeles, LA, USA, 2008.
10. He, X.; Xu, M.; Zhang, H.; Zhang, B.; Su, B. An exploratory study of the deterioration mechanism of ancient wall-paintings based on thermal and moisture expansion property analysis. *J. Archaeol. Sci.* **2014**, *42*, 194–200. [CrossRef]
11. Li, H.; Wang, W.; Zhan, H.; Qiu, F.; Guo, Q.; Sun, S.; Zhang, G. The effects of atmospheric moisture on the mural paintings of the Mogao Grottoes. *Stud. Conserv.* **2017**, *62*, 229–239. [CrossRef]
12. Li, Y.; Huang, Z.; Petropoulos, E.; Ma, Y.; Shen, Y. Humidity governs the wall-inhabiting fungal community composition in a 1600-year tomb of Emperor Yang. *Sci. Rep.* **2020**, *10*, 1–10. [CrossRef]
13. Bettini, G.; Massa, S. Preservation problems, visitors and deterioration on the painted Etruscan tomb. In *Science, Technology and European Cultural Heritage, Proceedings of the European Symposium, Bologna, Italy, 13–16 June 1989*; Baer, N.S., Sabbioni, C., Sors, A.I., Eds.; Butterworth-Heinemann Publishers: Guildford, UK, 1991; pp. 761–769. ISBN 978-0-7506-0237-2.
14. Pantazidou, A.; Roussomoustakaki, M.; Urzì, C. The microflora of Milos Catacombs. In *Archaeological Sciences 1995*, 1st ed.; Sinclair, A., Gowlett, J.A.J., Slater, E.A.S., Eds.; Owbow Books: Oxford, UK, 1997; pp. 321–325. ISBN 9781785708053.
15. Scatigno, C.; Gaudenzi, S.; Sammartino, M.; Visco, G. A microclimate study on hypogea environments of ancient roman building. *Sci. Total. Environ.* **2016**, *566*, 298–305. [CrossRef] [PubMed]
16. Mora, P.; Mora, L.; Philippot, P. *The Conservation of Wall Paintings*; Butterworths: London, UK, 1984; ISBN 0408108126.
17. Oligschläger, D.; Waldow, S.; Haber, A.; Zia, W.; Blumich, B. Moisture dynamics in wall paintings monitored by single-sided NMR. *Magn. Reson. Chem.* **2015**, *53*, 48–57. [CrossRef]
18. Monte, M.; Ferrari, R. Biodeterioration in subterranean environments. *Aerobiologia* **1993**, *9*, 141–148. [CrossRef]
19. Ariño, X.; Hernandez-Marine, M.; Saiz-Jimenez, C. Colonization of Roman tombs by calcifying cyanobacteria. *Phycologia* **1997**, *36*, 366–373. [CrossRef]

20. Saiz-Jimenez, I.G.C. Actinomycetes in Hypogean Environments. *Geomicrobiol. J.* **1999**, *16*, 1–8. [CrossRef]
21. Nugari, M.; Pietrini, A.; Caneva, G.; Imperi, F.; Visca, P. Biodeterioration of mural paintings in a rocky habitat: The Crypt of the Original Sin (Matera, Italy). *Int. Biodeterior. Biodegrad.* **2009**, *63*, 705–711. [CrossRef]
22. Albertano, P. Epilithic algal communities in hypogean environments. *G. Bot. Ital.* **1993**, *127*, 386–392. [CrossRef]
23. Bruno, L.; Belleza, S.; Urzì, C.; De Leo, F. A study for monitoring and conservation in the Roman Catacombs of St. Callistus and Domitilla, Rome (Italy). In *The Conservation of Subterranean Cultural Heritage*; Apple Academic Press: Palm Bay, FL, USA, 2014; pp. 37–44.
24. Capitani, D.; Proietti, N.; Gobbino, M.; Soroldoni, L.; Casellato, U.; Valentini, M.; Rosina, E. An integrated study for mapping the moisture distribution in an ancient damaged wall painting. *Anal. Bioanal. Chem.* **2009**, *395*, 2245–2253. [CrossRef] [PubMed]
25. Cultural Heritage and Aerobiology. In *Cultural Heritage and Aerobiology*; Springer Fachmedien Wiesbaden: Wiesbaden, Germany, 2003; pp. 207–224.
26. Ruga, L.; Orlandi, F.; Romano, B.; Fornaciari, M. The assessment of fungal bioaerosols in the crypt of St. Peter in Perugia (Italy). *Int. Biodeterior. Biodegrad.* **2015**, *98*, 121–130. [CrossRef]
27. Di Carlo, E.; Chisesi, R.; Barresi, G.; Barbaro, S.; Lombardo, G.; Rotolo, V.; Sebastianelli, M.; Travagliato, G.; Palla, F. Fungi and Bacteria in Indoor Cultural Heritage Environments: Microbial-related Risks for Artworks and Human Health. *Environ. Ecol. Res.* **2016**, *4*, 257–264. [CrossRef]
28. Bruno, L.; Rugnini, L.; Spizzichino, V.; Caneve, L.; Canini, A.; Ellwood, N.T.W. Biodeterioration of Roman hypogea: The case study of the Catacombs of SS. Marcellino and Pietro (Rome, Italy). *Ann. Microbiol.* **2019**, *69*, 1023–1032. [CrossRef]
29. KNUCH. *Study on the Preservation Methods of Mural Painting in the Ancient Tombs in Songsan-ri*; Gongju: Gongju City, Korea, 2012; pp. 108–156.
30. Chung, Y.J.; Lee, H.J.; Kim, H.M.; Kim, D.W. Study on the microbe growth characteristics by environmental condition of ancient tomb. In Proceedings of the 41th Conference of the Korean Society of Conservation Science for Cultural Heritage, Seoul, Korea, 27 March 2015; pp. 27–30.
31. Sprocati, A.R.; Alisi, C.; Tasso, F.; Vedovato, E.; Barbabietola, N.; Cremisini, C. A microbiological survey of the Etruscan Mercareccia tomb (Italy): Contribution of microorganisms to deterioration and restoration. In *Proceedings of the 9th International Conference on NDT of Art 2008, Jerusalem, Israel, 25–30 May 2008*; NDT of Art: Jerusalem, Israel, 2008; p. 9. Available online: www.ndt.net/search/docs.php3?MainSource=65 (accessed on 26 January 2021).
32. Tomassetti, M.C.; Cirigliano, A.; Arrighi, C.; Negri, R.; Mura, F.; Maneschi, M.L.; Gentili, M.D.; Stirpe, M.; Mazzoni, C.; Rinaldi, T. A role for microbial selection in frescoes' deterioration in Tomba degli Scudi in Tarquinia, Italy. *Sci. Rep.* **2017**, *7*, 1–8. [CrossRef]
33. Cirigliano, A.; Tomassetti, M.C.; Di Pietro, M.; Mura, F.; Maneschi, M.L.; Gentili, M.D.; Cardazzo, B.; Arrighi, C.; Mazzoni, C.; Negri, R.; et al. Calcite moonmilk of microbial origin in the Etruscan Tomba degli Scudi in Tarquinia, Italy. *Sci. Rep.* **2018**, *8*, 1–10. [CrossRef]
34. Isola, D.; Zucconi, L.; Cecchini, A.; Caneva, G. Dark-pigmented biodeteriogenic fungi in Etruscan hypogeal tombs: New data on their diversity and favouring conditions. *Fun. Biol.* **2021**, in press.
35. Isola, D.; Bartoli, F.; Langone, S.; Ceschin, S.; Zucconi, D.; Caneva, G. Plant DNA barcode as tool for root identification in hypogeans: The case of the Etruscan tombs of Tarquinia (Italy). *PLoS ONE* **2021**, in press.
36. Pallottino, M. *La Peinture Étrusque*; Flammarion: Geneva, Switzerland, 1952.
37. Marzullo, M. *Grotte Cornetane. Materiale e Apparato Critico per lo Studio Delle Tombe Dipinte di Tarquinia. Tarchna Suppl. 6*, 1st ed.; Ledizioni Ledi Publishing: Milano, Italy, 2016; ISBN 978-88-6705-484-8.
38. Cecchini, A. *Le Tombe Dipinte di Tarquinia. Vicenda Conservativa, Restauri e Tecnica di Esecuzione*, 2nd ed.; Nardini Editore: Firenze, Italy, 2012; pp. 15–102. ISBN 978-88-404-4347-8.
39. Kyriakou, V.T.; Panoskaltsis, V.P. Impact of the tumulus on the stability of microclimate in underground heritage structures. *Int. J. Sci. Eng. Technol.* **2019**, *4*. Available online: http://www.ijstre.com/v4i5.php (accessed on 26 January 2021).
40. Massa, S. Esigenze conservative di un ipogeo interessato da vegetazione sovrastante. In *Ruderi & Vegetazione. Questioni di Restauro*, 1st ed.; Mancini, R., Rossi Doria, I., Eds.; Ginevra Bentivoglio Editoria: Rome, Italy, 2017; pp. 265–289. ISBN 8899618577.
41. Mitrakos, K. A theory for Mediterranean plant life. *Acta Oecol. Sér. Oecol. Plant. Montreuil* **1980**, *1*, 245–252.
42. Raunkiaer, C. *Plant Life Forms*; The Clarendon Press: Oxford, UK, 1937.
43. Potenza, G.; Fascetti, S.; Castronuovo, D.; Lovelli, S.; Perniola, M.; Viggiani, R.; Rossi, R.; Marchione, V.; Can-dido, V. Collection and preliminary characterization of native turfgrass accessions of *Cynodon dactylon* L. in the Mediterranean area. *J. Food Agric. Environ.* **2014**, *12*, 770–774. [CrossRef]
44. Croce, P.; De Luca, A.; Mocioni, M.; Volterrani, M.; Beard, J.B. Warm season turfgrass species and cultivar characterizations for a Mediterranean climate. *Int. Turfgrass Soc. Res. J.* **2001**, *9*, 855–859.
45. Parson, D.L.P.; Lehman, V.G. Bermudagrass plant named "Premier". U.S. Patent PP18,247 P3, 27 November 2007.
46. Pesaresi, S.; Galdenzi, D.; Biondi, E.; Casavecchia, S. Bioclimate of Italy: Application of the worldwide bioclimatic classification system. *J. Maps* **2014**, *10*, 538–553. [CrossRef]
47. Mattias, P.P.; Ventriglia, U. La regione vulcanica dei Monti Sabatini e Cimini. *Mem. Soc. Geol. Ital.* **1970**, *9*, 331–384.
48. D'Agostino, S.; Lombardi, G.; Russo, G.; Viggiani, C. Structural engineering and geology applied to the static problems of the Etruscan "Tomba dell'Orco" (Tarquinia, Central Italy). *J. Cult. Herit.* **2010**, *11*, 107–112. [CrossRef]

49. Spizzichino, D.; Leoni, G.; Guarino, P.M.; Boldini, D.; Mengoni, S.; Marino, E.; Cecchini, A.; Trucco, F.; Casocavallo, B. Influenza delle condizioni climatiche sulla stabilità delle tombe etrusche della necropoli di Monterozzi a Tarquinia. In *Monitoraggio e Manutenzione delle Aree Archeologiche. Cambiamenti Climatici, Dissesto Idrogeologico, Degrado Chimico-Ambientale*, 1st ed.; Russo, A., Della Giovampaola, I., Eds.; «L'Erma» di Bretschneider: Roma, Italy, 2020; pp. 227–230. ISBN 9788891319470.
50. Braun-Blanquet, J. Plant Sociology. In *The Study of Plant Communities*; McGraw-Hill Book Co., Inc.: New York, NY, USA; London, UK, 1932.
51. Pignatti, S. *La Flora d'Italia*; Ed. Edagricole: Milano, Italy, 2017.
52. Bartolucci, F.; Peruzzi, L.; Galasso, G.; Albano, A.; Alessandrini, A.; Ardenghi, N.M.G.; Astuti, G.; Bacchetta, G.; Ballelli, S.; Banfi, E.; et al. An updated checklist of the vascular flora native to Italy. *Plant Biosyst. Int. J. Deal. Asp. Plant Biol.* **2018**, *152*, 179–303. [CrossRef]
53. Blasi, C.; Facioni, L.; Burrascano, S.; Del Vico, E.; Tilia, A.; Rosati, L. Submediterranean dry grasslands along the Tyrrhenian sector of central Italy: Synecology, syndynamics and syntaxonomy. *Plant Biosyst. Int. J. Deal. Asp. Plant Biol.* **2012**, *146*, 266–290. [CrossRef]
54. Diaz-Herraiz, M.; Jurado, V.; Cuezva, S.; Laiz, L.; Pallecchi, P.; Tiano, P.; Sanchez-Moral, S.; Saiz-Jimenez, C. The Actinobacterial Colonization of Etruscan Paintings. *Sci. Rep.* **2013**, *3*, srep01440. [CrossRef] [PubMed]
55. Diaz-Herraiz, M.; Jurado, V.; Cuezva, S.; Laiz, L.; Pallecchi, P.; Tiano, P.; Sanchez-Moral, S.; Saiz-Jimenez, C. Deterioration of an Etruscan tomb by bacteria from the order Rhizobiales. *Sci. Rep.* **2015**, *4*, 3610. [CrossRef] [PubMed]
56. Caneva, G. A botanical approach to the planning of archaeological, parks in Italy. *Conserv. Manag. Archaeol. Sites* **1999**, *3*, 127–134. [CrossRef]
57. Caneva, G.; Galotta, G.; Cancellieri, L.; Savo, V. Tree roots and damages in the Jewish catacombs of Villa Torlonia (Roma). *J. Cult. Herit.* **2009**, *10*, 53–62. [CrossRef]
58. Cicinelli, E.; Salerno, G.; Caneva, G. An assessment methodology to combine the preservation of biodiversity and cultural heritage: The San Vincenzo al Volturno historical site (Molise, Italy). *Biodivers. Conserv.* **2017**, *27*, 1073–1093. [CrossRef]
59. Caneva, G.; Benelli, F.; Bartoli, F.; Cicinelli, E. Safeguarding natural and cultural heritage on Etruscan tombs (La Banditaccia, Cerveteri, Italy). *Rend. Lincei Sci. Fis. Nat.* **2018**, *29*, 891–907. [CrossRef]
60. Caneva, G.; Cicinelli, E.; Scolastri, A.; Bartoli, F. Guidelines for urban community gardening: Proposal of preliminary indicators for several ecosystem services (Rome, Italy). *Urban For. Urban Green.* **2020**, *56*, 126866. [CrossRef]
61. Agarossi, G.; Ferrari, R.; Monte, M.; Gugliandolo, C.; Maugeri, T. Changes of microbial system in an Etruscan tomb after biocidal treatments. In Proceedings of the Vlth International Congress on Deterioration and Conservation of Stone, Torun, Poland, 12–14 September 1988; Nicolaus Copernicus University Press: Torun, Poland, 1988; pp. 82–91.
62. Agarossi, G. Biodeterioramento in ambienti ipogei: Esperienze e considerazioni. In *Studi e Ricerche sulla Conservazione delle Opere d'Arte Dedicati alla Memoria di Marcello Paribeni*; Guidobaldi, F., Ed.; CNR: Rome, Italy, 1994; pp. 1–18.
63. Ma, Y.; Zhang, H.; Du, Y.; Tian, T.; Xiang, T.; Liu, X.; Wu, F.; An, L.; Wang, W.; Gu, J.-D.; et al. The community distribution of bacteria and fungi on ancient wall paintings of the Mogao Grottoes. *Sci. Rep.* **2015**, *5*, 7752. [CrossRef]
64. Ma, W.; Wu, F.; Tian, T.; He, D.; Zhang, Q.; Gu, J.-D.; Duan, Y.; Ma, D.; Wang, W.; Feng, H. Fungal diversity and its contribution to the biodeterioration of mural paintings in two 1700-year-old tombs of China. *Int. Biodeterior. Biodegrad.* **2020**, *152*, 104972. [CrossRef]
65. Nugari, M.P.; Realini, M.; Roccardi, A. Contamination of mural paintings by indoor airborne fungal spores. *Aerobiologia* **1993**, *9*, 131–139. [CrossRef]
66. Monte, M.; Ferrari, R.; Massa, S. Biodeterioration of Etruscan tombs: Aerobiology and microclimate. In *Proceedings of the 5th International Conference, Bangalore, India, 1994*; Agashe, S.N., Ed.; Science Publishers: Norwood, NJ, USA, 1997; pp. 333–346. ISBN 9781886106840.
67. Caneva, G.; De Nuntiis, P.; Fornaciari, M.; Ruga, L.; Valenti, P.; Pasquariello, G. Aerobiology applied to the preventive conservation of cultural heritage. *Aerobiologia* **2019**, *36*, 99–103. [CrossRef]
68. Kim, D.W.; Jeong, S.H.; Lee, M.Y.; Chung, Y.J. Thermal Environment Analysis for Preserving Ancient Mural Painting in Songsan-ri Tomb No. 6, Gongju, Korea. *J. Conserv. Sci.* **2016**, *32*, 521–534. [CrossRef]