Micrometeorology of the agricultural terraces and stone walls and impacts on biodiversity in the Mediterranean landscape of Greece

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Abstract: Agricultural terraces and stone walls present a characteristic view of the Mediterranean landscape, and are vital in relation to the conservation of biodiversity, ecological functionality and cultural heritage. The aim of the study is to identify the contribution of micrometeorology of the agricultural terraces and stone walls, and impacts on the biodiversity of the Mediterranean landscape. The literature review survey indicates that terraces and stone walls provide various vital goods and services, and are potential and interesting assets for the development of the Greek areas. It is noteworthy that agricultural terraces and stone walls are an important habitat for biodiversity and they are creating multiple microenvironments enhancing its conservation and sustaining the stability of the ecosystem. Consequently, these landscape elements should be preserved as they favour the components of biodiversity, which are the source of our food and medicines, fibres, fuels and industrial products. The utilisation of the biodiversity components contributes substantially to the economy and the development of tourism.

Keywords: terraces; stone walls; climate; micrometeorology; flora; fauna; conservation; landscape; Greece; Mediterranean.

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1 Introduction

Greece is considered to be the centre of the Mediterranean biodiversity, and it is also accepted as a predominant biodiversity hotspot globally (Solomou and Sfougaris, 2021). A profound characteristic of Greece is its abundant fauna and flora, the high number of fungi species and a wide display of ecosystems and landscapes. There is high endemism as the high percentage of the species found in Greece are considered to be unique worldwide (Dimopoulos et al., 2013; 2016; Solomou and Sfougaris, 2021). Also, it contains a variety of climatic conditions, the ample coverage of natural and semi natural habitats, long coastlines and a wide and well documented variety concerning its topography with high aesthetic and cultural values (Solomou and Sfougaris, 2019). Greece hosts a variety of local climatic types, constantly changing within the last century, presenting shifts to more arid conditions (Tsiros et al., 2020). The country's complex topographic terrain, the diversity of altitudes, the great number of islands and the relative long coastal line compared to its area, result in a variety of local climates. Based on Thornthwaite's aridity index, Tsiros et al. (2020) analysed data from 91 meteorological stations and identified three main climatic types (humid, sub-humid and semi-arid) out of the five according to UNEP (1992) climate classification system.

Agricultural terraces and stone walls present a characteristic view of the Mediterranean landscape especially that of the Aegean islands. They are the largest and most common landforms that humans have ever produced. Terraces can be found on all inhabited continents and up to the 19th century CE they were the only major systematic and globally anthropogenic alteration to slopes. For this reason, agricultural terraces are probably the most obvious pointer of the "Anthropocene epoch" but paradoxically, their age (some being over 6,000 years old even the Hanging Gardens of Babylon belong to

agricultural terraces) presents problems concerning any formal distinction of the period they belong to (Brown et al., 2017; 2021).

Cultivation terraces and stone walls are a typical characteristic landscape element found all over the world (Grove and Rackham, 2002; Netting, 1993). They are pieces of sloped plane that have been cut into series of successively receding flat surfaces which resemble wide steps, in the Mediterranean area usually supported by a stone wall (Petanidou et al., 2008) and are used for effective farming, sustaining a variety of different land uses [e.g., cereals, vegetables, pulses, and other arable crops; vines and trees (orchards, chestnuts, nuts and olives); and grazing lands (sown with pulses or cereals), etc.]. Cultivation terraces and stone walls have a number of benefits concerning the environment and human societies, as the Ecosystem services they provide are vital. More specifically, the most important benefits are:

a control of soil erosion (caused by water or winds)

b protection against extreme weather events (flood prevention, strong winds, etc)

c creation of green infrastructure for island ecosystems, with multiple benefits for their adaptation to climate change

d creation of micro habitats suitable for the conservation, protection and enhancement of biodiversity

e production, under specific conditions, of high quality products

f enhancement of the high aesthetic and cultural value of the Mediterranean landscape (Koulouri, 2004; Krahtopoulou and Frederick, 2008; Petanidou, 2015).

In the Mediterranean of the 20th century, terraced olive plantations and vineyards were not abandoned to the degree of other terraced arable cultivations. This apparently happened because permanent plantations such as olive and vine plantations serve as a significant investment both in time and money and they can still provide high quality products for the consumers (Bevan et al., 2013; Solomou et al., 2020). In contrast, tillable cultivations were abandoned in preference to the easier to cultivate lowlands (Grenon and Batisse, 1989). Unfortunately, the abandonment of the terraces and the adoption of new, intensive types of crops resulted in the destruction of many of these stone structures (Petanidou et al., 2008). The immediate consequences are increased erosion (Cammeraat et al., 2005; Koulouri and Giourga, 2007) and reduced soil fertility (Gebremedhin et al., 1999; Vagen et al., 1999), elements that in some small islands caused total abandonment of agriculture (Bevan and Conolly, 2011; Van der Sluis et al., 2014).

Changes concerning the land use and generally the landscape at the farm scale can be resulted from the economic efficiency of the land/farm uses and other socioeconomic issues. Related research conducted worldwide targeting at the use of cultivation terraces has revealed common characteristics in otherwise different backgrounds (Kizos et al., 2010).

According to literature, Bakker et al. (2005) link on Lesvos (Greece) an intense change concerning the use of land and also the physical geological characteristics (relief-slope gradient) with soil erosion rates which consequently cause even more land changes. Terraces come first in their description, as they play an important role in the land use changes. Hill et al. (1998) cover the impacts of grazing on the island of Crete

and present the policy and socioeconomic forces concerning the need for grazing areas. Also, Petanidou et al. (2008) discuss another similar case on the Nisyros island (Aegean Sea) and explicate social and economic factors being the most important force pressing towards the almost complete cultivation neglect and landscape change, including the disintegration of terraces. Blanchemanche (1990) and Nixon (2001) present the most complete accounts concerning the cultivation terraces found in the Mediterranean area. In their studies we find a historical perspective of the role of cultivation on terraces and the reasons leading to the abandonment of this practice. The authors provide examples of various terraces styles and their functions from all the Mediterranean area. Furthermore, they thoroughly explain the causes of their neglect and its impacts (Kizos et al., 2010).

It is known that the cultivation of drystone terraces composes the most important large-scale human intervention on the landscape of the islands since the emergence of their civilisation. It is noteworthy that the art of stone walls in Greece was registered in 2018 in the representative list of UNESCO for the intangible cultural heritage of mankind (UNESCO, 2021). Nowadays, the creation of new terraces has ceased and their maintenance is negligible. For this reason, the Ministry of Rural Development via the Measure 4 entitled: "Investments for agricultural holdings and agricultural products" which constitutes one of the most important measures of the Greek Rural Development Program 2014–2020, funds the action 4.4.3 entitled: "Maintenance and construction of terraces" (Rural Development Program-RDP, 2014 – 2020).

The purpose of this paper is to review research regarding:

a the description of the manmade stone elements of the rural landscape

b the micrometeorology of terraces and stone walls

c the contribution of terraces and stone walls to biodiversity

d the possible impact of climate change.

2 Methodology

Literature review constitute a methodical penetration into the already existing knowledge regarding a specific topic selected by researchers (Botelho et al., 2011). The literature searches about the micrometeorology of the agricultural terraces and stone walls, and impacts on biodiversity in the Mediterranean landscape of Greece was decided to consider the period of the past 30 years with special consideration of the more recent literature (from year 1996 to 2021). This information was obtained using the main online scientific sites including Scopus, Google Scholar, PubMed, Science Direct and MEDLINE. Searches were also conducted in the dissertation and thesis search engines such as ProQuest, open-thesis and national documentation centre. The keywords important to the search, were: Mediterranean landscape, agricultural terraces, stone walls, micrometeorology, climate, biodiversity, flora, fauna, soil moisture, runoff, infiltration, erosion, transpiration, wind protection, soil fertility, Greece (Figure 1).

Figure 1 Word cloud of key-words. source: prepared by the authors using https://www.wordclouds.com/ (see online version for colours)

Papers published in International journals, books and websites served as literature sources. Keeping in mind that a literature review analyses, synthesises and critically evaluates in order to clarify the knowledge of a subject, full papers were downloaded when that was possible. When it was not feasible, the titles of these papers were googled and downloaded from other publication databases including the personal profiles of the researchers from social networking sites such as Research Gate and Academia edu (Solomou et al., 2019).

3 Description of the manmade stone elements of the rural landscape

During the last centuries the rural landscapes of the Mediterranean area have important alterations. Traditional Mediterranean agricultural topography featuring dry stonewalls and terraces is connected with the agricultural beginnings of most modern Mediterranean societies. It is noteworthy that terraces were constructed so as to increase the land for cultivation and preserve the natural resources of soil and water. Although their presence in the past is questionable, they can be detected in the 5th century BC (Foxhall, 1996) and even earlier, during the iron age (Grove and Rackham, 2002). They are present all over the Mediterranean basin (Grove and Rackham, 2002) in four types (Rackham and Moody, 1992):

a step, which can be found in a straight line or along the contours

b braided, which zigzag on the slope

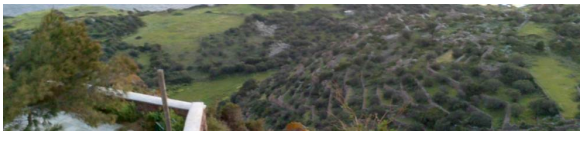
c pocket, which support individual trees

d dry stonewalls.

Figure 2 Agricultural drystone terraces in different Island Regions Of Greece, (a) Tinos, (b) Kythera (c–d) Milos (e) Kea (f) Naxos (see online version for colours)

(a)

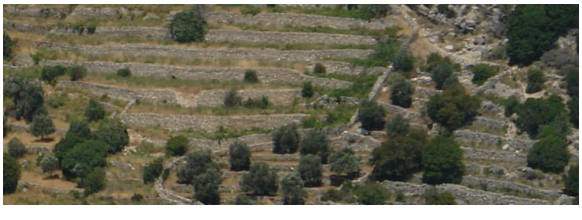
(b)



(c)

(d)

(e)



(f)

For the majority of the Aegean islands, the slow but steady increase concerning the population until the first quarter of the 20th century, led to their expansion to major parts of available areas. However, the rural "exodus" that followed this climax, brought about a certain neglect of agriculture on terraces and a gradual decline of their quality, if not their devastation. The first two types of terraces, supported various land uses, such as cereals, vegetables, pulses and other cultivable crops; vines and trees (orchards, chestnuts, nuts and olives); and also grazing lands (Kizos, 2003). The third type supported individual trees, especially olive trees covering the Aegean areas. Terraces are built with dry stonewalls having inverse triangle shape, while the shape above has been dug and filled with soil. The techniques differ according to the materials found locally (rock size-geology) and according to the local traditions. Last but not least traditional dry stonewalls are most commonly built as livestock fences in coastal areas and islands (built against grazing or for marking field limits) (Gasparis, 1997; Myriounis et al., 2015).

Figure 3 Agricultural drystone terraces in different mountainous regions of Arkadia-Greece (see online version for colours)

(a)

(b)

(c)

Figure 4 Agricultural drystone walls in different regions of Greece, (a–b) Naxos (c–d) Kea (see online version for colours)

(a)

(b)

(c)

(d)

Figure 5 Snails using the favourable microenvironment of a stone terrace in Naxos (see online version for colours)

4 Micrometeorology of terraces and stone walls

The improvement on soil water conditions in terraced sites was identified by many authors (i.e., Courtwright and Findlay, 2011; Zhang et al., 2017). Terracing enhances water infiltration and storage in soil and prevents runoff and erosion (Hammad et al., 2006; Perlotto and D'Agostino, 2018; Sandor, 1998; Stanchi et al., 2012). The establishment of vegetation has a serious influence on soil hydraulic characteristic and fertility through the increase of soil organic matter and also the functional role plant roots. Recent studies (Koulouri and Giourga, 2007; Romero-Diáz et al., 2017) indicate that in abandoned terraces colonised by natural vegetation the soil organic matter and infiltration was increased and runoff was decreased, compared to recently abandoned ones that were barely-covered with vegetation. Additionally in a very interesting review by Moreno-de-las-Heras et al. (2019) several key factors beyond vegetation cover are identified as important with positive influence on soil infiltration and runoff (e.g., stoniness, soil thickness, unequal distribution of soil depths within the terrace, surface crusting, vegetation disturbance, livestock grazing, wildfires, etc.) underlining the multiple benefits ensued from preserving traditional terraces and also the hydro-geomorphological consequences of their abandonment.

The soil moisture availability can highly influence the growth dynamics of the forest plant species (Brito et al., 2015; Čermák and Prax, 2001; Pataki et al., 2000; Proutsos et al., 2017), since it defines the available water in the rootzone that can be used by the plants. In the terraced sites soil depth is higher compared to that found at the slopes and thus soil can maintain and store more water for the plants. This is of high importance in rainfed (farming or forest) ecosystems and can define the plants establishment, survival and growth.

Especially in rainfed ecosystems the presence of stone walls and stone covered risers can influence the distribution of rainfall especially when rain drops fall with an angle against the stone elements. In such cases the eroding ability of rainfall water diminishes since the velocity of rain drops reach zero as they fall on the stone elements of the structure, moving vertically thereafter in the terrace surface. In this way, the water is added in the terrace and is slowly absorbed by the soil enhancing its moisture and infiltration rates without moving sediments. This is very important in cases of high intense precipitation but also effective when large amounts of precipitation fall in the terrace. In the second case, its sediment movements are possible, however, these movements are more likely to occur inside the terrace and rarely from one terrace to another.

In the Mediterranean zone, terraces receive precipitation of about 500–700 mm per year, 100% infiltrated (Ackermann, 1996; Lavee et al., 1998), that makes the terraces sustainable in terms of water availability for vegetation (Ackerman et al., 2019). However, in semi – arid and arid climates, the rocky environment enhances runoff, which can reach about 80-90% of precipitation (Yair and Kossovsky, 2002). In these cases, the terraces or soil pockets receive the amounts of water from the direct precipitation and also the additional water from the runoff, allowing water harvesting for sustaining vegetation growth and survival (Ackermann et al., 2019).

Relevant studies on the micrometeorology of terraces and stones walls are very rare, especially those dealing with the impacts on the growth dynamics of plants and specifically under the Mediterranean environmental conditions. In a recent study, Zhang et al. (2017) assessed the effect of terracing on soil water content and canopy

transpiration in a pine (Pinus tabulaeformis) plantation in a semi-arid site in China and compared terraced and sloped sites during two subsequent years with different precipitation levels. This climatic type is very similar to many regions of the Aegean Sea Cyclades Islands complex, Evia (a neighbouring island to Attica), Attica basin and Crete (Tsiros et al., 2020; Proutsos et al., 2021). Zhang et al. (2017) identified that during the relatively wet year, the soil water content was by 25.4% higher at the terraced sites compared to the slope and the daily transpiration rates (during the growing period) were enhanced by about 9.1%. Canopy conductance was also found to increase by 3.9% and sup flow rates were also by 20.2% higher, whereas flood runoff and sediment transportation was decreased. Similarly, Shen et al. (2015) for the same species found canopy transpiration and conductance values by 6.9% and 3.9% higher at the terraced sites compared to the slope sites, respectively.

Sunlight distribution in the agricultural terraces, compared to the relatively more smooth continuous slopes, considerably differs since the roughness of the terraced slope is increased allowing the multiple scattering of the radiation beams. The usually stone covered riser of the terrace also influences the optical properties of the surface, altering its energy budget. These sunlight patterns vary both on a diurnal and on seasonal basis, considering the direction of the radiation beams and the intensity and spectral composition of the direct and diffuse solar radiation fluxes (Liakatas et al., 2002; Proutsos et al., 2019), allowing the formation of a variety of microenvironments even on the same terrace with shadowed and sunny, hotter and cooler, humid or drier micro-areas that can enhance both flora and fauna diversity.

The impact of terraced environment in wind direction and speed is also an important issue. The terraced slopes, as already mentioned, are characterised by the increased roughness of the surface compared to the untouched slopes. The roughness will increase by the construction elements height and density, enhancing friction and resulting in lower wind speeds near the ground. In this way agricultural terraces and especially stone walls contribute to the protection of the plants from strong winds or even from heat waves and drought events that can affect their growth dynamics and are common phenomena even at the high mountainous sites of the Greek Peninsula (Proutsos et al., 2010; Proutsos and Tigkas, 2020). It should also be noted that wind movements and especially its vertical component, highly affect the energy (solar radiation, heat) and mass (carbon, vapor) fluxes and thus the photosynthetic rates, with impacts on the surface productivity. Additionally, the orientation of the stone elements can alter the direction of winds adding also to the protection of the vegetated surfaces.

5 Contribution of terraces and stone walls to biodiversity

Greece is considered as a ‘hot spot’ concerning biodiversity. More than 7,000 native plant taxa are found in Greece with 20% of them being endemic. The vascular flora of Greece embraces 5,885 species and 2,000 subspecies (native and naturalised) which in turn, represent 6,760 taxa, belonging to 1,087 genera and 184 families (Dimopoulos, 2013; 2016). The Greek flora is unique in Europe mainly for its abundance and its large

analogy of endemic species and their relevant ecosystems. Geographically Greece is set among three continents (Europe, Asia, Africa) and together with factors such as a mild Mediterranean climate, intense relief, vast beaches, numerous islands and a most interesting palaeogeographical history provides unique and ideal habitats for Europe and the planet (CBD, 2010).

As far as the Greek fauna is concerned, 23,130 species of land and freshwater animals have been recorded, of which 3,956 are endemic and 3,500 are marine species (Fauna Europaea Web Service, 2004; Legakis and Maragkou, 2009). Over the last 30 years scientific research on macromycete diversity in Greece has shown that around 3,000 species have been sporadically recorded in the country (Topalidou et al., 2021). There is also a large diversity of the Greek flora, reflecting the diversity of its fauna. It is known that during the Ice Age, the Hellenic territory sheltered animals coming down from N. Europe. Another important fact is the large variety of habitats found in relatively small areas, which contributed to the creation of individual populations of wildlife evolved into new species and subspecies, thus creating endemism (CBD, 2010).

Terraces and stone walls present a characteristic view of the Mediterranean landscape especially that of the Aegean islands. In many cases, they create ecological habitats, offering temporary or permanent refuge to various biodiversity components such as flora, invertebrates, reptiles, birds, etc. This very orientation of the terraces to the south may create fire risks, nevertheless these retaining walls store heat during the day, releasing it at night thereby 'creating a local microclimate' necessary for many organisms, resulting in the increase of biodiversity (Vernikos et al., 2001). These constructions-landscape mosaics create an artificial habitat and organism shelter proving to be an important guardian of biodiversity. At the base of the terraces and the stone walls an ideal environment is created with high humidity and increased primary productivity. These factors are important for the abundance and diversity of soil arthropods population (e.g., spiders, coleoptera, etc.) (Arnelt et al., 2002; Dajoz, 2002; Pafilis et al., 2014).

Furthermore, according to the study which took place in three Aegean islands (Andros, Naxos, Milos), along with invertebrates, the populations of certain reptile's species are favoured, especially lizards, which showed very large population concentrations in the terraces and stone walls (Pafilis, 2014).

Finally, during the summer period, the slits and openings found on the stone walls accommodate another species, the shelled gastropods, protecting them during their breeding period. This probably has to do with the moisture 'blocked' there and the increased calcium deposits most useful for the construction of their shells, factors contributing to the welfare of these organisms (Manenti, 2014). Other frequent 'visitors' are the reptiles, whose exothermic condition is the key in their selection of suitable sites where they can find warmth, rich food and protection (Adolph, 1990) and for these reasons find stone terraces very attractive. It is important to note that these areas are of paramount importance for wildlife because they provide an important refuge for species which constitute important food for many bird species.

Figure 6 Plants using the favourable microenvironment of stone terraces in Aegean islands, (a–c) Kythera (d–e) Nisyros (f) Andros (see online version for colours)

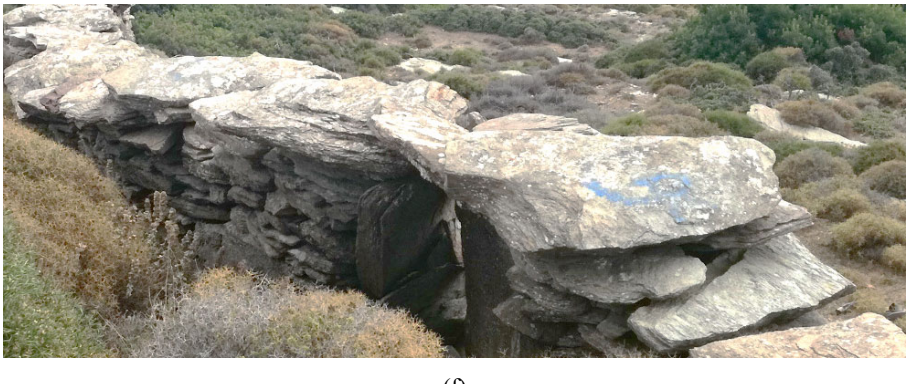
(a)

(b)

(c)

(d)

(e)



(f)

Another proof of their importance is the fact that dry and shady plants find ideal conditions there, as these terraces host species that are scattered by the natural flora of the neighbouring areas. Also, terraces and stone walls are also a refuge for plant species whose natural habitats are under pressure, such as cliffs and crevices (Varti-Matarangas and Katsikis, 2002). The degree of plant species coverage vary greatly from place to place depending on the micro-geographical conditions (microclimate, altitude, etc.) (Petanidou, 2001). Other factors concerning the growth of herbaceous plants on terraces, are the age/condition of the construction, its orientation, moisture retention and shading of the area, all of which regulate their health (Pafilis, 2014).

Also, Darlington's (1981) contention that small animals sheltering in walls distribute the seeds of zoophilous plants around wall bases, fact that favours the plant species composition. Furthermore, Lesschen et al. (2008) refer that the secondary succession after abandonment commences initially with annual or biannual plants and is followed by perennial forbs, grasses and shrubs. This might be a possible explanation for the diversity of species seen in terraces and stone walls.

Van Ruijven and Berendse (2005) refer in their study that the main function of the terrace soils was to increase productivity and when abandoned, the level of the disturbance has not been severe compared to other disturbances (although the remaining soils generally offer characteristics for natural regeneration). These satisfactory conditions increase, produce and in some cases can be associated with greater diversity (Loreau et al., 2002). Likewise, the higher vegetation cover in the terraces may be related to the better soil conditions, particularly the higher water and nutrient availability. The study presents that the composition of species cannot be differentiated although it is quite true that some species are characteristic of either the abandoned terraces or the non-terraced natural soil. Several factors may explain this absence of differentiation: the existing distances between the natural grounds and the terraces favour colonisation, providing a good and nearby source of propagules. Therefore, even after disuse, these characteristics remain suitable for colonisation on the terraces (Stanchi et al., 2012).

6 Possible impact of climate change

The role of terraces is different with regard to the climatic zones that they appear. In more arid climates with low precipitation, they were created to preserve the fertile soil and to enhance soil water availability in order to have sustainable and more productive agricultural systems. In most humid climates with high precipitation its role is also important in enhancing infiltration and for flood prevention.

It is important to discriminate the traditional agricultural terraces from the modern land terracing techniques. In an interesting work, Ramos et al. (2007) assessed the sustainability of modern constructed terraces in the Priorat region of SE Spain for viticulture, underlining the difference with the traditional terraces. The authors mention that shortly after the construction of the modern terraces with mechanical means, extended and irreversible landslides occurred, attributing the failures to the criteria adopted for the construction of the terraces, which was only trafficable without considering the movement of water or other environmental and climate-related factors.

The Greek climate is characterised by decreasing precipitation on a magnitude of 15% the recent climatic period (1961–1997) compared to the past (1931–1960), with also increasing (+9%) water deficits in the dry period and decreasing (+38%) water surplus

during the wet period of the year (Tsiros et al., 2020). The above pattern and mainly the rapid increase in water deficit during the dry period of the year and the decrease in water surplus at the wet period, is expected to influence the water availability for vegetation in Greece with higher risk in the Greek islands which are characterised by more arid conditions. In these cases, the preservation of the stone terraces is of critical importance for sustaining the already stressed natural vegetation. The abandonment and collapse of the terraces has been already occurring along with overgrazing and the changing climate is expected to result in a significant degradation of the natural vegetation. Accordingly, the stressed vegetation will not be able to contribute to the protection of the terraces (and their favourable environment for plants). All the above, introduce an urgent need for implementing actions for the conservation and protection of stone terraces and walls which can be considered as a climate friendly – nature based solution for climate change adaptation and mitigation, since their construction from the farmers of the past was implemented in order "to adapt to different climate conditions and take advantage of the natural systems" as stated by Ackermann et al. (2019). It is a fact that even nowadays, drystone terraces are being used and preserved in several Greek areas (e.g., Arkadia, Crete, Cyclades, Korinthos, Kythera, Lymnos) because their inhabitants live by farming on these terraces. As a result, the preservation of the terraced landscapes depends on the local farmers, so they should be energetically involved in the matters having to do with terraced farming. More specifically, they should become part of the decision-making concerning appropriate strategies for ensuring the continuity and efficacy of these cultural landscapes of the Greek locale.

7 Conclusions

Terraces and stone walls are part of the landscape's cultural tradition and heritage and even contribute to the financial development of the local communities. Based on an environmental view, they create suitable micro-environments for biodiversity and enhance its conservation. Nowadays, there is the current trend concerning an effort to preserve cultural topographic characteristics and actually whole landscapes. It is true that these landscape changes have deprived islands and generally the Mediterranean area of local knowledge such as stone building, land, and biodiversity management. This is a major loss in productive, ecological, and symbolic terms as progressively the true potential of local varieties and management systems is realised in modern production systems. Hence, terraces and stone walls are essential to be preserved as a measure for the protection of the local flora and fauna and for strengthening ecosystems adaptation mechanisms in order to cope with climate change. Further research could help to clarify that the conservation and re-cultivation of terraces can work as green infrastructure (e.g., through environmental and biological indicators monitoring, climate change projections, etc.), an effort that is going to revitalise and modernise the primary sector, rending it multifunctional as well as economically and environmentally sustainable.

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References

Ackermann, O. (1996) *Effect of Biogenic Crust on Infiltration and Erosion Process along a Climatological Gradient*, MA Thesis, Department of Geography, Bar Ilan University, Israel.

Ackermann, O., Zhevelev, H.M. and Svoray, T. (2019) 'Agricultural systems and terrace pattern distribution and preservation along climatic gradient: from sub-humid Mediterranean to arid conditions', *Quaternary International*, Vol. 502, No B., pp.319–326.

Adolph, S.C. (1990) 'Influence of behavioral thermoregulation on microhabitat use by two Sceleporus lizards', *Ecology*, Vol. 71, No. 1, pp.315–327.

Arnelt, R. Jr, Thomas, M.C., Skelley, P.E. and Frank, J.H. (2002) *American Beetles, Volume II: Polyphaga: Scarabaeoidea through Curculionoidea*, CRC Press LLC, Boca Raton, FL.

Bakker, M.M., Govers, G., Kosmas, C., Vanacker, V., Oost, K. van and Rounsevell, M. (2005) 'Soil erosion as a driver of land-use change', *Agriculture, Ecosystems and Environment*, Vol. 105, No. 3, pp.467–481.

Bevan, A. and Conolly, J. (2011) 'Terraced fields and Mediterranean landscape structure: an analytical case study from Antikythera, Greece', *Modelling*, Vol. 222, No. 7, pp.1303–1314.

Bevan, A., Conolly, J., Colledge, S., Frederick, C., Palmer, C., Siddall, R. and Stellatou, A. (2013) 'The long-term ecology of agricultural terraces and enclosed fields from Antikythera, Greece', *Human Ecology*, Vol. 41, No. 2, pp.255–272.

Blanchemanche, P. (1990) *Bâtisseurs de paysages: Terrassement, épierrement et petite hydraulique agricoles en Europe XVIIe-XIXe siècles*, p.329, Les Editions de la MSH, Paris, ISBNs: 2735103714, 9782735103713.

Botelho, L.L.R., Cunha, C.C.A. and Macedo, M. (2011) 'O metodo da revisao integrativa nos estudos organizacionais', *Gestao e Sociedade*, Vol. 5, No. 11, pp.121–136.

Brito, P., Lorenzo, J.R., González-Rodríguez, Á.M., Morales, D., Wieser, G. and Jiménez, M.S. (2015) 'Canopy transpiration of a semi-arid pinus canariensis forest at a treeline ecotone in two hydrologically contrasting years', *Agricultural and Forest Meteorology*, Vol. 201, pp.120–127.

Brown, A.G., Fallu, D., Walsh, K., Cucchiaro, S., Tarolli, P., Zhao, P., Pears, B.R., van Ooste, K., Snape, L., Lang, A., Albert, RM., Alsos, I.G. and Waddington, C. (2021) 'Ending the Cinderella status of terraces and lynchets in Europe: the geomorphology of agricultural terraces and implications for ecosystem services and climate adaptation', *Geomorphology*, Vol. 379, DOI: 107579.

Brown, A.G., Tooth, S., Bullard, J.E., Thomas, D.S.G., Chiverrell, R.C., Plater, A.J., Murton, J., Thorndycraft, V.R., Tarolli, P., Rose, J., Wainright, J. and Downs, P. (2017) 'The geomorphology of the Anthropocene: emergence, status and implications', *Earth Surface Processes and Landforms*, Vol. 42 No. 1, pp.71–90.

Cammeraat, E., van Beek, R. and Kooijman, A. (2005) 'Vegetation succession and its consequences for slope stability in SE Spain', *Plant and Soil*, Vol. 278, No. 1, pp.135–147.

CBD (2010) *Decision X/2, The Strategic Plan For Biodiversity 2011–2020 And The Aichi Biodiversity Targets,* pp.18–29 October 2010, Nagoya, Japan.

Čermák, J. and Prax, A. (2001) 'Water balance of a Southern Moravian floodplain forest under natural and modified soil water regimes and its ecological consequences', *Annals of Forest Science, EDP Sciences*, Vol. 58, No. 1, pp.15–29.

Courtwright, J. and Findlay, S.E.G. (2011) 'Effects of microtopography on hydrology, physicochemistry, and vegetation in a tidal swamp of the Hudson River', *Wetlands*, Vol. 31, No. 2, pp.239–249.

Dajoz, R. (2002) *Les Coléoptères: Carabidés Et Ténébrionidés*, Tec and Doc Lavoisier, Paris Londres New York (N.Y.), ISBNs: 2743005394, 978-2743005399.

Darlington, A. (1981) *Ecology of Walls*, Heinemann Educational, London.

Dimopoulos, P., Raus, T., Bergmeier, E., Constantinidis, T., Iatrou, G., Kokkini, S., Strid, A. and Tzanoudakis, D. (2013) 'Vascular plants of Greece: an annotated checklist', *Berlin: Botanischer Garten und Botanisches Museum Berlin-Dahlem*, Vol. 31, pp.1–370, Freie Universität Berlin, Athens Hellenic Botanical Society, Englera.

Dimopoulos, P., Raus, T., Bergmeier, E., Constantinidis, T., Iatrou, G., Kokkini, S., Strid, A. and Tzanoudakis, D. (2016) 'Vascular plants of Greece: an annotated checklist supplement', *Willdenowia*, Vol. 46, No. 3, pp.301–347.

Fauna Europaea Web Service (2004) *Fauna Europaea Version 1.1* [online] http://www.faunaeur.org (accessed 24 March 2021).

Foxhall, L. (1996) 'Feeling the earth move: cultivation techniques on steep slopes in classical antiquity', in Shapley, G., Salmon, J. (Eds.): *Human Landscapes in Classical Antiquity: Environment and Culture*, Routledge, London.

Gasparis, H. (1997) Land and Farmers in Medieval Crete: 13th–14th Centuries, *National Research Foundation*, Athens (in Greek).

Gebremedhin, B., Swinton, S.M. and Tilahun, Y. (1999) 'Effects of stone terraces on crop yields and farm profitability: Results of on-farm research in Tigray, northern Ethiopia', *Journal of Soil and Water Conservation, Soil and Water Conservation Society*, Vol. 54, No. 3, pp.568–573.

Grenon, M. and Batisse, M. (1989) *Futures for the Mediterranean Basin: The Blue Plan, UNEP-MAP/BP-RAC* [online] https://stg-wedocs-new.unep.org/handle/20.500.11822/2149 (accessed 24 March 2021).

Grove, A.T. and Rackham, O. (2002) *The Nature of Mediterranean Europe: An Ecological History*, Yale University Press, New Haven.

Hammad, A.H.A., Børresen, T. and Haugen, L.E. (2006) 'Effects of rain characteristics and terracing on runoff and erosion under the Mediterranean', *Soil and Tillage Research*, Vol. 87, No. 1, pp.39–47.

Hill, J., Hostert, P., Tsiourlis, G., Kasapidis, P., Udelhoven, Th. and Diemer, C. (1998) 'Monitoring 20 years of increased grazing impact on the Greek island of Crete with earth observation satellites', *Journal of Arid Environments*, Vol. 39, No. 2, pp.165–178.

Kizos, T. (2003) *Agricultural Landscape Dynamics: Estimation Of Spatial Impacts Of Common Agricultural Policy In Rural Aegean Islands*, PhD Thesis, Department of Environmental Studies, University of the Aegean, Greece (in Greek).

Kizos, T., Dalaka, A., and Petanidou, T. (2010) 'Farmers' attitudes and landscape change: evidence from the abandonment of terraced cultivations on Lesvos, Greece', *Agriculture and Human Values*, Vol. 27, No. 2, pp.199–212.

Koulouri, M. (2004) *Soil Water Erosion and Land Use Change in the Mediterranean: Abandoning Traditional Extensive Cultivation*, PhD Thesis, Environment Department, University of the Aegean, Mytilene, Greece (In Greek).

Koulouri, M. and Giourga, Chr. (2007) 'Land abandonment and slope gradient as key factors of soil erosion in Mediterranean terraced lands', *CATENA*, Vol. 69, No. 3, pp.274–281.

Krahtopoulou, A. and Frederick, C. (2008) 'The stratigraphic implications of long-term terrace agriculture in dynamic landscapes: polycyclic terracing from Kythera Island, Greece', *Geoarchaeology: An International Journal*, Vol. 23, No. 4, pp.550–585.

Lavee, H., Imeson, A.C. and Sarah, P. (1998) 'The impact of climate change on geomorphology and desertification along a Mediterranean-arid transect', *Land Degradation and Development*, Vol. 9, No. 5, pp.407–422.

Legakis, A. and Maragkou, P. (2009) *The Red Book of Endangered Animals of Greece,* p.528, Hellenic Zoological Society, Athens.

Lesschen, J.P., Cammeraat, L.H. and Nieman, T. (2008) 'Erosion and terrace failure due to agricultural land abandonment in a semi-arid environment', *Earth Surface Processes and Landforms*, Vol. 33, No. 10, pp.1574–1584.

Liakatas, A., Proutsos, N. and Alexandris, S. (2002) 'Optical properties affecting the radiant energy of an oak forest', *Meteorological Applications*, Vol. 9, No. 4, pp.433–436.

Loreau, M., Naeem, S. and Inchausti, P. (2002) *Biodiversity and Ecosystem Functioning: Synthesis and Perspectives*, p.294, Oxford University Press on Demand, New York.

Manenti, R. (2014) 'Dry stone walls favour biodiversity: a case-study from the Appennines', *Biodiversity and Conservation*, Vol. 23, No. 8, pp.1879–1893.

Moreno-de-las-Heras, M., Lindenberger, F., Latron, J., Lana-Renault, N., Llorens, P., Arnáez, J., Romero, A. and Gallart, F. (2019) 'Hydro-geomorphological consequences of the abandonment of agricultural terraces in the Mediterranean region: key controlling factors and landscape stability patterns', *Geomorphology*, Vol. 333, pp.73–91.

Myriounis, C., Varras, G., Tsirogiannis, I. and Pavlidis, V. (2015) 'Usage of stone materials in natural and human environment, case study in Epirus, Greece', *Agriculture and Agricultural Science Procedia*, Vol. 4, pp.431–439.

Netting, R.M. (1993) *Smallholders, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture*, Stanford University Press, Stanford.

Nixon, L. (2001) 'A.T. Grove and O. Rackham, The Nature of Mediterranean Europe. an ecological history, New Haven and London: Yale University Press, 2001. pp.384, numerous illus', *The Journal of Roman Studies,* Cambridge University Press, Vol. 91, pp.196–197.

Pafilis, P. (2014) 'Dry stone, biodiversity supports', Scientific Research Program 2013, Ioannis, S. (Ed.): *Latsis Public Benefit Foundation*, National and Kapodistrian University of Athens, Greece (In Greek).

Pataki, D.E., Oren, R. and Smith, W.K. (2000) 'Sap flux of co-occurring species in a Western Subalpine forest during seasonal soil drought', *Ecology*, Vol. 81, No. 9, pp.2557–2566.

Perlotto, C. and D'Agostino, V. (2018) 'Performance assessment of bench-terraces through 2-D modelling', *Land Degradation and Development*, Vol. 29, No. 3, pp.607–616.

Petanidou, T. (2001) *The Role of Terraces in the Past and Their Importance for the Future of the Islands in Terms of Economy, Ecology and Culture*, Final Technical Report to the Ministry of the Aegean, Mytilene, Greece.

Petanidou, T. (2015) *Terraces of the Aegean – the example of Dodecanese*, pp.280, Parisianou Scientific Publications, Athens, (In Greek).

Petanidou, T., Kizos, T. and Soulakellis, N. (2008) 'Socioeconomic dimensions of changes in the agricultural landscape of the Mediterranean basin: a case study of the abandonment of cultivation terraces on Nisyros Island, Greece', *Environmental Management*, Vol. 41, No. 2, pp.250–266.

Proutsos, N. and Tigkas, D. (2020) 'Growth response of endemic black pine trees to meteorological variations and drought episodes in a Mediterranean Region', *Atmosphere*, Vol. 11, No. 6, p.554.

Proutsos, N., Liakatas, A. and Alexandris, S. (2019) 'Ratio of photosynthetically active to total incoming radiation above a Mediterranean deciduous oak forest', *Theoretical and Applied Climatology*, Vol. 137, No. 3, pp.2927–2939.

Proutsos, N., Liakatas, A., Alexandris, S. and Tsiros, I. (2017) 'Carbon fluxes above a deciduous forest in Greece', *Atmósfera*, Vol. 30, No. 4, pp.311–322.

Proutsos, N., Tsagari, K., Karetsos, G., Liakatas, A. and Kritikos, T.H. (2010) 'Recent temperature trends over mountainous Greece', *European Water*, Vol. 2010, No. 32, pp.15–23.

Proutsos, N.D., Tsiros, I.X., Nastos, P. and Tsaousidis, A. (2021) 'A note on some uncertainties associated with Thornthwaite's aridity index introduced by using different potential evapotranspiration methods', *Atmospheric Research*, 105727.

Rackham, O. and Moody, J. (1992) 'Terraces' in *Proceedings of the Seventh International Symposium on Agriculture in Ancient Greece*, Swedish Institute in Athens, Stockholm.

Ramos, M.C., Cots-Folch, R. and Martínez-Casasnovas, J.A. (2007) 'Sustainability of modern land terracing for vineyard plantation in a Mediterranean mountain environment – the case of the priorat region (NE Spain)', *Geomorphology*, Vol. 86, No. 1, pp.1–11.

Romero-Díaz, A., Ruiz-Sinoga, J.D., Robledano-Aymerich, F., Brevik, E.C. and Cerdà, A. (2017) 'Ecosystem responses to land abandonment in Western Mediterranean Mountains', *CATENA*, Vol. 149, No. 3, pp.824–835.

Rural Development Program (RDP) (2014 – 2020) *Ministry of Rural Development and Food* http://www.agrotikianaptixi.gr/el/content/metro-4-ependyseis-se-georgikes-ekmetalleyseis-kai-gia-georgika-proionta (accessed 12 March 2021).

Sandor, J. (1998) 'Steps toward soil care: ancient agricultural terraces and soils' in *Proceedings of 16th Word Congress of Soil Science*, Montpellier, France, p.6.

Senn-Irlet, B., Heilmann-Clausen, J., Genney, D. and Dahlberg, A. (2007) 'Guidance for the conservation of mushrooms in Europe', *Convention on the Conservation of European Wildlife and Natural Habitats. 27th Meeting*, Strasbourg, November, Vols. 26–29, pp.34.

Shen, Q., Gao, G., Fu, B. and Lü, Y. (2015) 'Responses of shelterbelt stand transpiration to drought and groundwater variations in an arid inland river basin of Northwest China', *Journal of Hydrology*, Vol. 531, No. 3, pp.738–748.

Solomou, A., Proutsos, N., Karetsos, G. and Tsagkari, K. (2020) 'Impact of stone terraces and walls micro-environment on biodiversity conservation: a case study in the Mediterranean Island of Kythira-Greece', in *HAICTA 2020: Proceedings of the 9th International Conference on Information and Communication Technologies in Agriculture, Food and Environment*, Thessaloniki, Greece, pp.549–557.

Solomou, A.D. and Sfougaris, A. (2019) 'Predicting woody plant diversity as key component of ecosystems: a case study in Central Greece', *International Journal of Agricultural and Environmental Information Systems*, Vol. 10, No. 1, pp.1–20.

Solomou, A.D. and Sfougaris, A. (2021) 'Contribution of agro-environmental factors to yield and plant diversity of olive grove ecosystems (Olea europaea L.) in the Mediterranean landscape', *Agronomy*, Vol. 11, No. 1, p.161.

Solomou, A.D., Topalidou, E.T., Germani, R., Argiri, A. and Karetsos, G. (2019) 'Importance, utilization and health of urban forests: a review', *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, Vol. 47, No. 1, pp.10–16.

Stanchi, S., Freppaz, M., Agnelli, A., Reinsch, T. and Zanini, E. (2012) 'Properties, best management practices and conservation of terraced soils in Southern Europe (from Mediterranean areas to the Alps): a review', *Quaternary International*, Vol. 265, pp.90–100.

Topalidou, E., Lagiotis, G. and Madesis, P. (2021) 'Morphological and molecular identification confirms the occurrence of the rare macromycete Phaeolepiota aurea in Greece', *Austrian Journal of Mycology*, Vol. 28, pp.123–130.

Tsiros, I.X., Nastos, P., Proutsos, N.D. and Tsaousidis, A. (2020) 'Variability of the aridity index and related drought parameters in Greece using climatological data over the last century (1900–1997)', *Atmospheric Research*, Vol. 240, DOI: 104914.

UNEP. (1992) *World Atlas of Desertification*, Edward Arnold, London.

UNESCO (2021) *Art Of Dry Stone Walling, Knowledge And Techniques - Intangible Heritage - Culture Sector* [online] http://ich.unesco.org (accessed 5 March 2021).

Vagen, T.G., Tilahun, Y. and Esser, K.B. (1999) 'Effects of stone terracing on available phosphorus and yields on highly eroded slopes in Tigray, Ethiopia', *Journal of Sustainable Agriculture*, Vol. 15, No. 1, pp.61–74.

Van der Sluis, T., Kizos, T. and Pedroli, B. (2014) 'Landscape change in Mediterranean farmlands: impacts of land abandonment on cultivation terraces in Portofino (Italy) and Lesvos (Greece)', *Journal of Landscape Ecology*, Vol. 7, No. 1, pp.23–44.

van Ruijven, J. and Berendse, F. (2005) 'Diversity-productivity relationships: initial eVects, long-term patterns, and underlying mechanisms', in *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 102, pp.695–700.

Varti-Matarangas, M. and Katsikis, Y. (2002) 'The building stone in monuments', in *Proceedings Interdisciplinary Workshop*, Athens, Greece, pp.187–210 (In Greek).

Vernikos, N., Daskalopoulou, S. and Paylogeorgatos, G. (2001) 'Proposal for classification of stone structures', in Varte-Matarangas, Katselis Y. (Ed.): *The Building Stone in Monuments. Paper presented at the International Interdisciplinary Workshop Scientific Conference ICOMOS – IGME 2001*, p.170270, Mytilene, Greece.

Yair, A. and Kossovsky, A. (2002) 'Climate and surface properties: hydrological response of small arid and semi-arid watersheds', *Geomorphology*, Vol. 42, No. 1, pp.43–57.

Zhang, H., Wei, W., Chen, L. and Wang, L. (2017) 'Effects of terracing on soil water and canopy transpiration of Pinus tabulaeformis in the Loess Plateau of China', *Ecological Engineering*, Vol. 102, pp.557–564.