AGRICULTURAL TERRACED SYSTEMS OF THE TUSCAN ARCHIPELAGO: TYPOLOGICAL ANALYSIS AND RECOVERY POSSIBILITIES OF DRY STONE WALLS

Paolo Armanasco, Leonardo Conti, Michele Moretta, Alberto Masoni, Stefano Camiciottoli, Enrico Palchetti

Abstract: In the islands of the Tuscan Archipelago, dry-stone walls represent an extensive cultural heritage in state of generalized abandonment. Considering the multifunctionality recognized to surviving terraced systems needs to be safeguarded through surveys aimed at providing characterization and indications for possible recovery interventions. After a preliminary quantitative G.I.S. remote analysis, qualitative characterization of the realities deemed most significant was carried out by on-site surveys. 48 sample areas have been analysed by studying parameters related to constructive, functional aspects and state of conservation. A variety of construction and management techniques has been found and it appears that there are strong differences in the state of conservation even between neighboring fields: on one side farmers and virtuous private individuals who maintain the terraces, on the other side, abandoned areas where the decay produces a fragmentation of the landscape continuity and originates sometimes non-negligible potential danger situations. Thus, technical indications are proposed for the restoration of degraded structures requiring priority interventions.

Keywords: dry stone walls, features analysis, state of conservation, land abandonment

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Introduction

Dry-stone works are the result of centuries of hard work and a stone culture that has developed in the various territories in relation to the peculiarities of the natural and socio-economic resources, as well as the changing historical circumstances, thus maturing formal expressions closely linked to the place [11]. Dry-stone walls typically are used to delimit properties, protect the growth and development of plants by creating favourable microclimates, interrupt the slope's steepness in order to control erosive phenomena on cultivable land, regulate water and create structures for the accumulation of soil and interstitial water [6] the latter being key factors in Mediterranean areas characterised by water scarcity in the summer months and intense rainfall with often destructive effects [10]. The concomitance of a number of factors, such as the abundance of suitable stone material without the possibility of valid alternatives, the need to build structures for soil defence and shelter in uncomfortable conditions, lead to the construction of this type of artefacts.

The vast majority of stone terraces that we observe today originated in the late 1800s and early 1900s [12], partly because older artefacts were demolished by natural agents due to abandonment or by man himself. The spread of terracing practices cannot be separated, in Italy as in the rest of the Mediterranean basin, from that of crops and the main agricultural techniques. It is evident that the development of fallow agriculture, i.e. an alternation on the same plot of land of annual crops for one or more years with a more or less long period of use as meadow-grazing, has favoured the arrangement of slopes with long-lasting structures [11]. Another decisive factor for the spread of terracing was population growth and hence human pressure to wrest more and more land from nature for the production of foodstuffs, especially in those territories, such as the Tuscan Archipelago, where the conformation of the terrain does not provide large flat areas or easy access.

The shapes and sizes of dry-stone terraces are quite variable and every terracing [1], like every site, has its own specificity in that it is an expression of the different ways in which the relationship between man and nature has manifested itself over time: "it constitutes a unicum, limited, perishable, unrepeatable, it has "its own process of development, its own history... reflecting the societies and cultures that conceived it, built it, used it or, in any case, came into contact with it", as the Italian Charter for Historic Gardens states [7].

The theme of the terraced landscape includes, in addition to the theme of historical and cultural heritage, the constituent dynamics of sustainable development in its local and territorial declination [13], interacting transversally with extremely topical issues such as hydrogeological defence [2], agriculture and food quality, the conservation of natural habitats [5] and rural tourism [14]; all interconnected elements that are adherent to the territorial reality of the Tuscan Archipelago. It is also an undeniable fact that the abandonment of terracing and slope arrangements in general speeds up the onset of hydro-geological instability phenomena and exacerbates their consequences in the short-medium term on the economic and social structure of the territories concerned.

In order to effectively direct future maintenance work, the Tuscan Archipelago National Park (PNAT) commissioned DAGRI (the Department of Agricultural,

Food, Environmental and Forestry Science and Technology of the University of Florence) to carry out a project entitled *'Detailed study of the heritage of dry-stone walls in the Tuscan Archipelago'*. This project aimed to study terraced agricultural areas through territorial analysis (mapping and geomorphological variables) and characterization of the typological characteristics of the stone artefacts. In addition to these aspects, technical advice has been provided on how to protect and restore damaged terrace systems. The evidence discussed in this article is a selection from the extensive discussion in the publication that was produced at the end of the study on behalf of the PNAT.

Material and Methods

The archipelago is located off the Tuscan coast, between Livorno and the Argentario promontory. The main islands that make up the archipelago are seven and cover about 300 km^2 (Gorgona 2.23 km^2, Capraia 19.3 km^2, Elba 223.5 km^2, Pianosa 10.2 km^2, Montecristo 10.4 km^2, Giglio 21.2 km^2, Giannutri 2.6 km^2). All the islands, except Pianosa and Giannutri, have a lively and mostly steep relief, although they reach modest heights.

Given the size and complexity of the area analysed, a quantitative analysis methodology was developed for the preliminary identification of the more representative areas in terms of terracing intensity indices. This made it possible to focus the research on the most significant areas of the territory and above all on the areas of greatest public interest (e.g. public roads and highly frequented areas), subsequently characterising the individual systems identified in qualitative terms. The research protocol was developed in 3 main phases sequential to each other.

The first phase, that is the quantitative analysis of the terraced systems was conducted in a GIS (Geographic Information System) environment, using the QGIS software for the management of the information layers required for the spatial analysis.

Using this information, the boundaries of the future sampling areas were traced, which are in any case to be considered not perfectly adherent to the actual boundaries of the areas surveyed (often some areas were found to be simply inaccessible due to natural and/or anthropic barriers), but rather as an indication of areas of territory in which to find similarities in conformation, as well as a way to better manage the volume of sites surveyed (Figure 1).

Forty-eight sample areas were identified in which to carry out field surveys. More specifically: 25 on the island of Elba, 6 on Capraia, 10 on Giglio, 4 on Pianosa, 2 on Gorgona. Given the reduced extension on Giannutri, a single area was defined (1). The preliminary topographical analysis on Montecristo did not provide enough evidence to justify carrying out qualitative field surveys.

In the second phase, each site within the identified areas deemed representative was investigated during the on-site survey operations in order to obtain qualitative and typological characterization. In situ data collection was carried out through the compilation of a survey form prepared by means of a dedicated smartphone application (JotForm) or alternatively in a hard copy version.

The on-site visits in this phase (Figure 2) were essential to gather information

that could not be found through the cartographic survey that characterized the first phase of analysis (e.g. construction aspects, cover vegetation state of conservation, as well as its actual extension). In total, an area of 40 km^2 was surveyed.

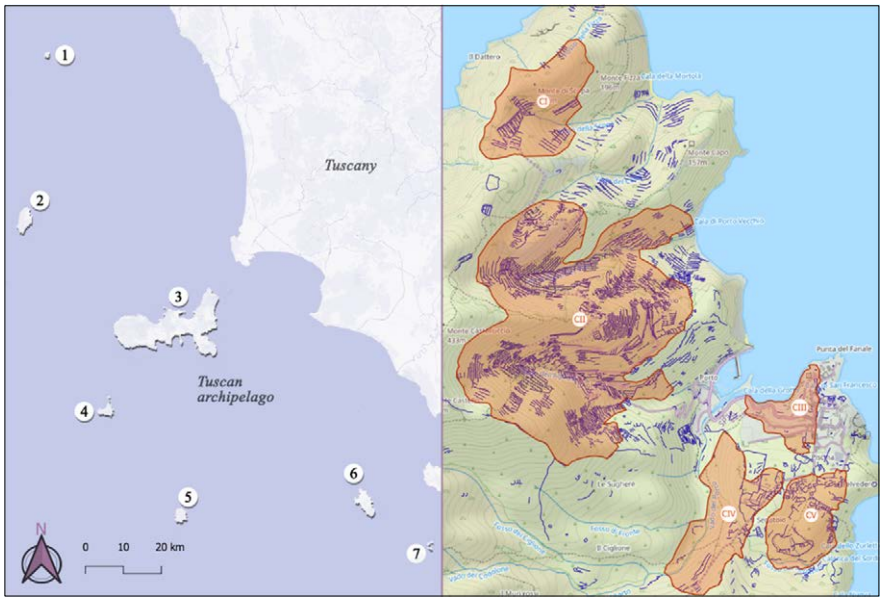

Figure 1 – Cartographic localization of the archipelago (left) and the preliminary definition of the sample areas conducted with QGIS software (right, Capraia island). The islands are: (1) Gorgona, (2) Capraia, (3) Elba, (4) Pianosa, (5) Montecristo, (6) Giglio, (7) Giannutri.

The photographic survey of the interesting and less accessible sample terraces was carried out using a drone or UAV (Unmanned Aerial Vehicle). Over the last 10-15 years, drones have become increasingly important for civil and technical applications, partly due to the development of photogrammetric techniques. The application of photogrammetric and UAV techniques makes it possible to produce georeferenced orthophotos and three-dimensional terrain models. A Mavic 2 Pro (DJI) drone with a forward speed of 5m/s was used to survey the terraced agricultural areas. Each flight mission was planned using the DJI GS Pro software in terms of height above ground, camera resolution and speed.

Using the cartography produced as part of the preliminary study (1° phase) and adding the topographic data collected in the field (2° phase), maps of each island were produced showing the location of surveyed sites. Detailed maps have also been produced within the descriptive sheet produced for each of the sample areas summarising the qualitative data collected These sheets are the result of the synthesis of the qualitative data collected.

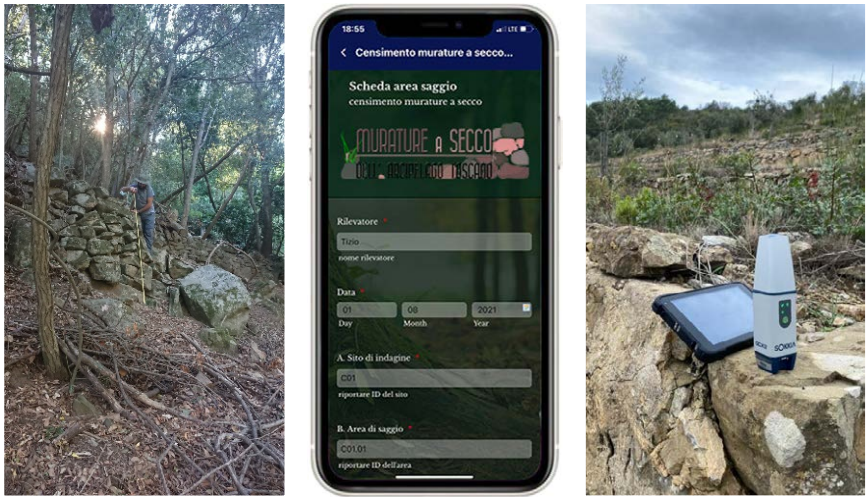

Figure 2 – Data collection operations in the second phase: manual measurement of dimensional parameters, data form on the smartphone application and drone accessories.

In the third phase, the organization on an electronic database of the data collected in the field allowed their subsequent numeric analysis and synthesis representation through graphs. The information thus synthesized provides an overall picture that briefly describes the consistency and state of conservation of the Tuscan Archipelago's dry-stone masonry heritage.

Results

The results of this study are numerous and varied. Firstly, useful maps have been produced to identify the most interesting terraced areas in the Tuscan Archipelago. A second important achievement is the production of a description sheet for each of the areas identified, which, in addition to locating the sites studied during the fieldwork on detailed maps, provides useful information on the type of wall studied, the state of conservation, the proximity of paths and whether it falls within the boundaries of the Tuscan Archipelago National Park. The numerical analysis of these data then made possible to graphically summarise most important information from the census and focus on critical points. Last but not least, all the aspects that need to be taken into account when carrying out maintenance or reconstruction work on dry-stone walls have been studied, from the technical to the regulatory aspects.

The 48 sample areas identified cover a total area of 4075 ha analysed, which represents about 15 % of the total area of the Tuscan Archipelago. A total of 394 sites were surveyed on site and analysed. 58 % of them are located in the territory of the National Park of the Tuscan Archipelago.

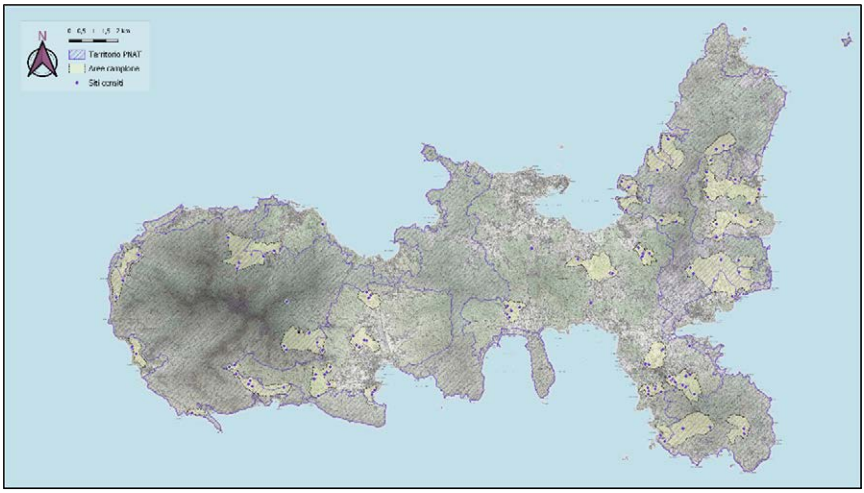

Figure 3 – Map of the Island of Elba showing the 25 areas with 30 sites surveyed.

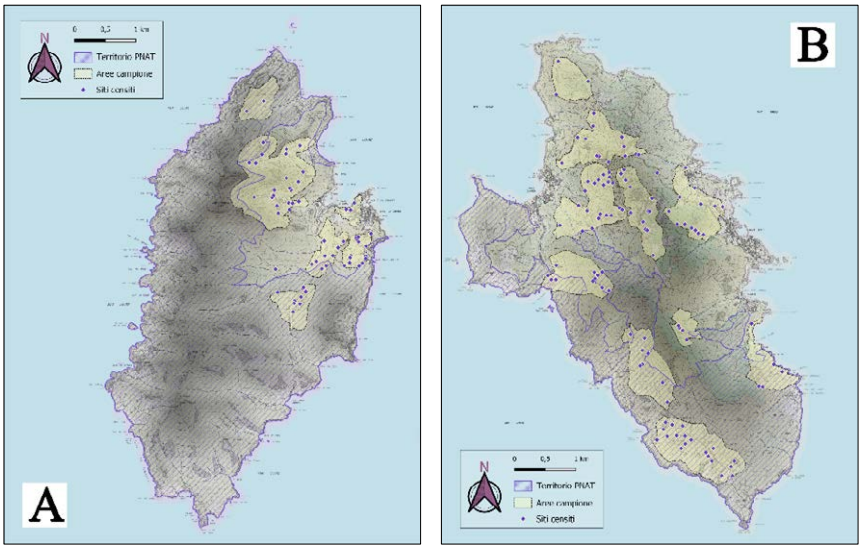

Figure 4 – Map of the Islands of Capraia (A) and Giglio (B) showing 6 sample areas with 60 sites on Capraia and 10 sample areas with110 sites on Giglio.

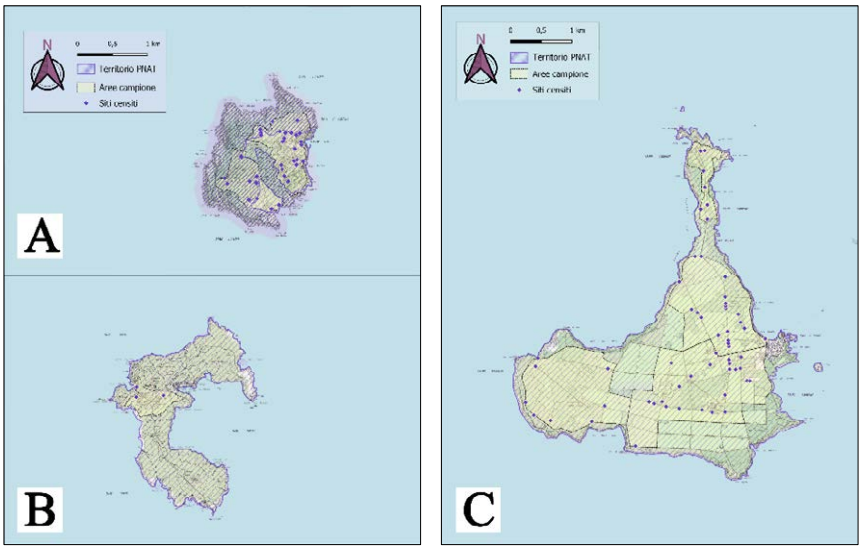

Figure 5 – Map of the Islands of Gorgona (A), Giannutri (B) and Pianosa (C). Maps shows localization of: 2 sample areas with 32 sites on Gorgona, 1 sample area with 3 sites on Giannutri, 4 sample areas with 59 sites on Pianosa.

Three basic types of dry-stone wall were identified in the present study: terracing (t), road support (rs) and boundary perimeter (bp). These typologies identify different functions for which the masonry was built. 58 % of the sites surveyed fall within the territory of the Tuscan Archipelago National Park (PNAT).

Table 1 – Number and typology of sites surveyed during the second phase of the field survey.

	Sites	Dry-stone wall typology		
Island	number	t	rs	bp
Elba	130	40 %	46 %	14 %
Giglio	110	49 %	16 %	35 %
Capraia	60	42 %	36 %	22 %
Pianosa	59	5 %	15 %	80 %
Gorgona	32	55 %	37 %	8 %
Giannutri	3	33%	0 %	67%
Total	394	153	120	119

Although three types of dry-stone walling have been identified, only the first two will be analysed here below, as they are typical of the context of terraced slopes and most uniformly characterising the agricultural landscape of the area under examination, as well as the usually considered in the sector literature. Moreover,

all these structures can be considered as a whole, since even the walls used to support the road infrastructure are, in most cases, one of the steps that make up a more complex terracing system, and are therefore fully comparable with those that precede and/or follow them along the slope. No graphs are shown for two islands. In particular, Pianosa because there are almost exclusively walls with a boundary function (the island is flat), Giannutri because of the paucity of data collected (drystone walls are practically absent here).

The data presented are organised as follows: from left to right, for each island there are graphs about the shape and size of the stone elements (grey), the cover of vegetation on the terraces and walls (green), the state of conservation and the causes of any deterioration (blue).

The grey graph shows a division between (A) opus incertus and (B) opus polygonal and a division between (a) small, (b) medium and (c) large stones. The green graph shows a subdivision between (V) spontaneous vegetation, (C) crops and (N) no vegetation and a subdivision between types of spontaneous vegetation, i.e. (a) tree, (b) shrub (c) herbaceous and (m) mixed. The blue graph shows a division between (I) intact and (D) damaged masonry and a classification of the causes of degradation, namely (a) natural, (b) anthropogenic and (c) mixed.

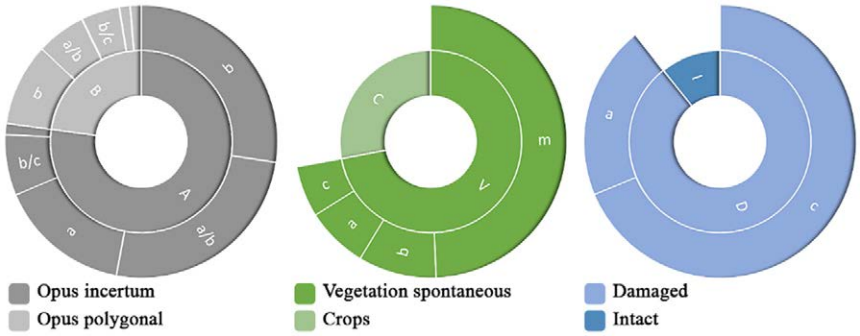

Figure 6 – Graphical summary of data for the island of Elba.

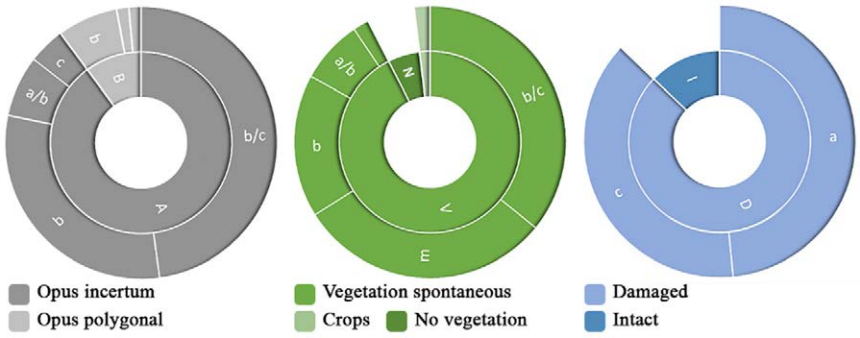

Figure 7 – Graphical summary of data for the island of Capraia.

On Elba Island (Figure 6), 77 % of the masonry is characterized by opus incertum (A), 23 % is polygonal (B) and in 37 % of cases, the stones are of medium size (b). Spontaneous vegetation (V) is present in 72 % of the surveyed sites and is mainly (49 %) of mixed type (m). 77 % of the surveyed masonry shows degradation (D), which in 59 % of cases has mixed causes (c).

On Capraia Island (Figure 7), 90 % of the masonry is characterized by opus incertum (A), 10 % is polygonal (B) and in 49 % of cases the stones are of medium-large size (b/c). Spontaneous vegetation (V) is present in 92 % of the surveyed sites and is mainly (38 %) of herbaceous/arbustive type (b/c). 87 % of the surveyed masonry shows degradation (D), which in 48 % of cases has natural causes (a).

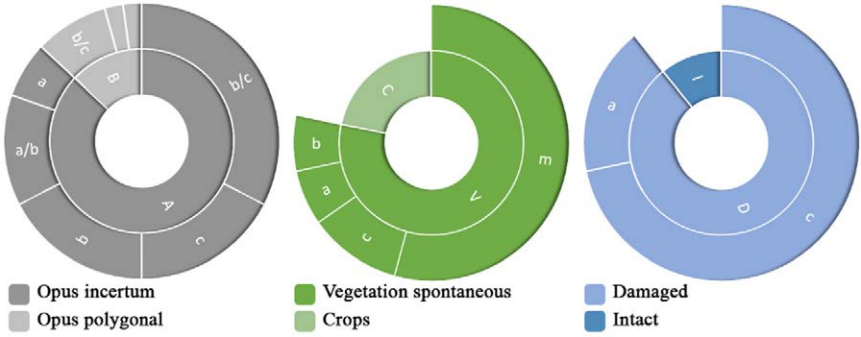

Figure 8 – Graphical summary of data for the island of Giglio.

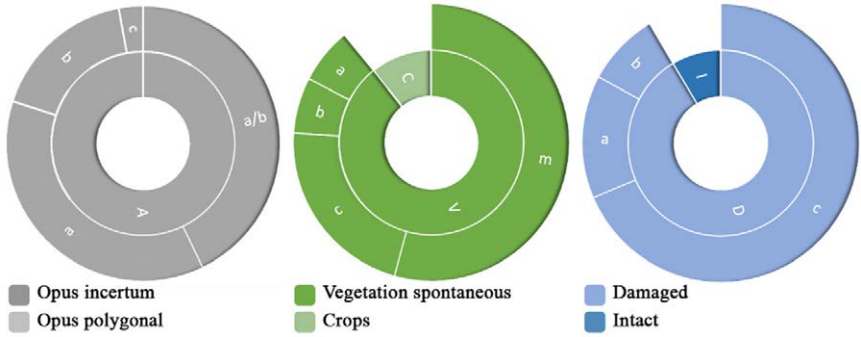

Figure 9 – Graphical summary of data for the island of Gorgona.

On Giglio Island (Figure 8), 87 % of the masonry is characterised by opus incertum (A), 13 % is polygonal (B) and in 41 % of cases the stones are of medium-large size (b/c). Spontaneous vegetation (V) is present in 78 % of the surveyed sites and is mainly (54 %) of mixed type (m). 89 % of the surveyed masonry shows degradation (D) with mainly (71 %) mixed causes (c).

On Gorgona Island (Figure 9), 100 % of the masonry is characterized by opus incertum (A) with little (a) (37 %) or little-medium (a/b) size (43 %) stones. Spontaneous vegetation (V) is present in 80 % of the surveyed sites and is mainly (60 %) of mixed type (m). 91 % of the surveyed masonry shows degradation (D), which in 68 % of cases has mixed causes (c).

Speaking about the actions that can be taken in order to maintain or restore dry stone walls, here below is reported a resume of main technical indications that have been identified within the present study.

Table 2 – Type and frequency of maintenance actions identified.

Type	Required action	Frequency
Regular inspections	1. Verify proper placement of crown stones, especially where wildlife passages occur.	3 months
	2. Verification of drainage system operation after heavy rain event.	3 months
Routine maintenance	1. Removal of vegetation that has grown in wall crevices; mature shrubs should not be uprooted to avoid damage to the structure: better an extensive pruning repeated until the vegetative potential is exhausted.	6 months
	2. Mowing of herbaceous vegetation close to the wall.	6 months
	3. Cleaning of the gullies at the foot to remove any obstructions present. Stormwater runoff must be ensured.	6 months
Occasional maintenance	1. Crowning and/or interstitial re-texturing.	when required
	2. Resolution of minor collapses if they occur.	when required
Corrective actions	Demolition and reconstruction of a section of wall with significant deterioration (spalling or collapse). Requires specialized manpower.	when required

Discussion

Regarding the first graph (grey), the size of the stone elements was assessed by counting the number of stones falling within the area represented by a 50 x 50 cm grid. Specifically, a situation was defined as small if the number of stones within the area was greater than or equal to 6, medium if it was between 6 and 3, and large if it was less than or equal to 3 stones per 0.25m² (50 x 50 cm). However, this is an average parameter derived from the need to obtain homogeneous information on a reality that is in fact very variable. Furthermore, the predominant stone geometry is opus incertum as found in peninsular Tuscany [1].

Speaking about the causes of deterioration, a condition common to varying degrees in 80 % of the walls surveyed, it is clear that they are due to natural or mixed factors. In particular, the following were considered to be natural causes: (1) the presence and/or passage of wild animals (especially ungulates, whose pressure is increasing with the progressive fields abandonment); (2) the establishment of spontaneous vegetation (which, on the one hand, can prevent soil erosion on the slopes but, on the other hand, causes the walls to crumble where the root systems penetrate between the stone elements); (3) the hydrostatic pressure exerted by the soils behind the

retaining walls, exacerbated by the progressive reduction in their drainage capacity.

The causes of mixed deterioration are those resulting from a combination of factors leading to instability, such as (1) reduction in drainage capacity (silting and vegetation encroachment are the main causes), (2) collapse of the walls of the upper terraces (in the case of terraced systems), (3) erosion. It should be noted that there is always an anthropic component at the basis of these phenomena, with reference to poor management, or the absence of the same (abandonment). This is confirmed by the substantial absence of purely anthropogenic causes of degradation (grazing animals, tree cutting, use/transit of machinery) resulting from some activity carried out in the areas investigated and with particular reference to the terraced areas. Furthermore, it should be noted that while many areas appear to be maintained (mown grass and vineyards or olive groves), the dry-stone walls supporting the terraces are often collapsed or almost completely buried. With rare exceptions, therefore, intact dry-stone walls are found only on farms that derive a direct economic benefit from their costly maintenance and/or have the technical skills to carry it out.

Elba Island, the largest of the archipelago, presents a great heterogeneity of environments and situations due to the conformation of the territory, but also to processes of anthropization of the territory that are clearly more marked and invasive than on the other islands. There is a widespread condition of abandonment and degradation of the terraces that are no longer being cultivated, but also of the numerous masonries supporting the public road system or in its immediate vicinity.

On the island of Capraia the hydraulic-agrarian arrangements are concentrated within the former agricultural ex penal colony, which constitutes one of the most significant territorial emergencies. Because of their extension, typology and quality of the construction model, which have allowed them to be maintained despite decades of neglect, these terraces can be considered an exceptional historical and cultural testimony, also of great landscape importance. Other masonry and terraces were already present in the past in other parts of the island, the result of centuries of work by generations of islanders: these are the sites where the most significant degradation has been observed as they were frequently abandoned in earlier times.

Today, a large part of the land management system based on dry-stone walls has been abandoned on Giglio island, with many remains still visible. The terraces still in use are mainly vineyards and a large part of the remaining terraces are on environmental mosaics in which tree crops play an important role. Therefore, the preservation of these structures strictly depends on the continued existence of viticulture. The abandonment process is at an advanced stage of evolution towards woodland. However, the nature of the soils and the climate of the area make it possible to envisage a recovery in many of these situations.

For the conservation of terraced areas, constant ordinary maintenance works would be desirable (replacement of stone elements, cutting of weed shrub vegetation, cleaning of the main elements and accessories of the hydraulic system) rather than extraordinary maintenance interventions necessary where structural alterations occur widespread of the system itself (medium-large landslides). Restoration should be carried out in these cases using traditional dry stone construction techniques. Interventions, based on incorrect design choices and inadequate construction techniques, can trigger erosion and instability phenomena that are even more dangerous than those from which they originated.

The lack of knowledge of traditional construction practices, connected to the difficulty of handing them down by elderly farmers, suggests adopting interventions by land management bodies (e.g. Park authorities, Unions of Municipalities) to transmit a knowledge system dedicated to the actors involved. These concepts based on "know-how" may be transmitted through technical laboratories to be used for the specialized training of craftsmen and operators who will thus be able to collaborate with public institutions and farms for territory maintenance works. On the contrary, where traditional practices are not known, the applications of Nature-based Solutions are sustainable alternative solutions capable of guaranteeing high standards of functionality to terraced landscapes, albeit partially altering the distinctive characteristics of each territory.

Finally, concerning cost, those associated with drystone masonry construction or rehabilitation work are notoriously high, related, above all, to the high specialization of labor minimum 70 % incidence of the total cost) and the time required for the realization. To be specific, For the execution of maintenance operations, cost items refer to: (a) labor, (b) materials, (c) transportation of materials, (d) site organization, (e) administrative requirements.

That is why, in light of the analysis conducted as part of this study, cost optimization for dry stone wall restoration is based primarily and as far as possible on the following conditions:

1. the manpower is that of the farm or owner;
2. the material used for construction comes from the pre-existing wall or is easy to find locally;
3. the use of materials from other areas should be kept to a minimum, both to minimize transportation costs and for landscape reasons (different shapes and coloration of stone elements.

Labor is the main cost item for these works and is used for the demolition of the deteriorated parts and their reconstruction. With regard to the demolition of the deteriorated parts, the excavation on the back and foundation, and the stacking of the resulting material, it is difficult to make general estimates of manpower needs, since they are conditioned by the actual site situations: in certain cases, where space permits, part of this work can be done with small mechanical means, with great savings in execution time, but with the need to estimate the costs of using or renting such machines.

Given the prevailing geological nature of the rocks of the Tuscan Archipelago, the stone material used for drystone walls (apart from notable exceptions such as on Capraia and Pianosa) is traditionally small to medium-sized, irregular and labor-intensive to lay. Minimal processing and/or its frequent absence (opus incertus), on the other hand, saves time and labor otherwise used for a more careful selection of stone elements and their processing.

In order to return a complete survey, prices coherent with the current labor market were assumed. For the estimation, what is present in the “Price List of Works of Tuscany 2024” (published by Regional Resolution n.1384 of 27-11-2023 and freely available online) and the experience gained by some experts in the field surveyed in this regard were taken into account.

On the understanding that the information given is to be considered indicative

because it does not include the specifics of individual intervention realities and because it analyzes cost items that are subject to annual variations, it is correct to assume a cost of 400-650 €/m^3 for ex novo construction and 200-300 €/m^3 for drywall restoration. The wide ranges are determined by the fact that cost items change according to the height of the work and thus the degree of complexity of the intervention. In addition, the costs we report are to be intended for interventions carried out with material collected on site and, therefore, net of any transportation expenses for the stones.

Conclusion

The survey returns a rather problematic snapshot of the current state of conservation and functionality of vast areas in the Tuscan Archipelago where the presence of dry-stone walls is marked. This is a symptom of a more general dynamic of abandonment of the territory. There are also marked differences between neighbouring areas in the same territory: on the one hand there are farms and willing private individuals who maintain the walls and terraces, and on the other, there are abandoned public and/or private areas where aggressive colonisation by spontaneous vegetation and the crumbling of the walls (by atmospheric agents and wildlife), once efficient, is causing erosion and instability. This heterogeneous situation produces a fragmentation of the continuity of the landscape and gives rise, especially near built-up areas and public roads, to situations of potential danger.

Given the size of the area in question, and given that over time many socio-economic factors have disappeared, which drove the local populations to extend the terraced areas to a great extent, it is simply unthinkable today to recover and maintain the entire heritage of dry-stone walls. However, it is possible and desirable to recover and maintain many masonry walls located near built-up areas and areas with a considerable impact on the landscape and, therefore, also subject to tourism. In these sites, a constant punctual intervention on the masonry is appropriate rather than exceptional interventions aimed at recovering large portions of walls or entirely rebuilding retaining walls, even if only damaged in some places.

Within the sphere of possible interventions to counter the current dynamic of land abandonment and degradation, the Clever Land on Elba, Capraia and Giglio Islands (CLEI) Integrated Territorial Project (PIT) deserves mention. The project, financed with funds from the PSR 2014-2020 of the Region of Tuscany, has brought together multiple actors, both public (including PNAT itself) and private, proposing the integration of the evolution of the territory with the pre-existing textures, at the same time improving the ecosystem value of the rural territory.

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