original scientific article
received: 2016-01-11

DOI 10.19233/ASHS.2016.29

INVESTMENT IN LANDESQUE CAPITAL IN SEMIARID ENVIRONMENTS: DRY-STONE TERRACES IN LES OLUGES (LA SEGARRA, CATALUNYA)

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ABSTRACT

The objective of this paper is to evaluate a methodology to assess the extent and state of conservation of the dry-stone wall terraces in the municipality of Les Oluges (La Segarra, Catalunya) (1915 ha). We described seventy seven 10 x 50 m plots distributed on a grid within the municipality. Stone walls were present in 30% of the sampling plots. The mean length of stone walls was 7.6 m per plot while derelict walls occupied another 7.1 m. Stone walls in agricultural fields appeared deteriorated more frequently than those under non-agricultural use. The standing dry--stone wall network of the terraced system in Les Oluges has, at present, a total length of about 87 km and involves over 144,000 Mg of rock fragments.

Keywords: landesque capital, social metabolism, soil conservation, soil erosion

INVESTIMENTI NEL CAPITALE DEI PAESAGGI ANTROPIZZATI IN ZONE SEMIARIDE: TERRAZZAMENTI SORRETTI DA MURI A SECCO A LES OLUGES (SEGARRA, CATALOGNA)

SINTESI

Lo scopo del presente contributo è esaminare una metodologia per valutare l'estensione e lo stato di conservazione dei terrazzamenti con muri di contenimento in pietra a secco nel comune di Les Oluges (nella comarca di Segarra, Catalogna) (1915 ettari). Sono stati analizzati 77 lotti di dimensioni 10 x 50 m distribuiti su uno schema all'interno del comune. I muri in pietra erano presenti nel 30% dei lotti inclusi nel campionamento. La lunghezza media dei muri in pietra era di 7,6 m per lotto, i muri in rovina ne occupavano altri 7,1 m. I muri in pietra situati nei campi agricoli risultavano deteriorati più spesso di quelli destinati a usi non agricoli. L'attuale rete di muri a secco ancora in piedi nell'ambito del sistema di terrazzamento di Les Oluges ha una lunghezza totale di circa 87 km ed è composta da oltre 144.000 tonnellate di frammenti rocciosi.

Parole chiave: capitale dei paesaggi antropizzati (*landesque capital*), metabolismo sociale, conservazione del suolo, erosione dei suoli

INTRODUCTION

The Mediterranean region includes a high proportion of hill and mountain areas that has produced a historical requirement to invest high amounts of labour and resources in landesque capital (Blaikie, Brookfield, 1987) in order to create relatively flat land surfaces that have been protected through various techniques (e.g., soil bunds, dry-stone terraces) to accommodate agricultural production. A rich biocultural heritage has been passed through centuries, including both material and immaterial structures, that needs to be preserved but which is frequently ignored by European public policies (Agnoletti, 2006, 2014).

This heritage is the result of the dynamic interaction between society and nature, that is, of the social metabolism (Toledo, 2013; Tello et al., 2016), and therefore, change is an inherent characteristic of terraced landscapes (Antrop, 2003; de Réparaz, 2007; Clark, Tsai, 2009). Although there is much debate about how far back in history stone terraces were used (Price, Nixon, 2005), there are certain features, ecologic and socioeconomic, that are common to the dynamics of terraced landscapes. The geomorphological instability that made them necessary in the first place requires a continuous investment in the maintenance of the walls (Blanchemanche, 1990) and is always a threat to their survival (Asins-Velis, 2007; Bevan et al., 2013; Boixadera et al., 2016). The changing socioeconomic conditions of societies have been the driving factors of such dynamics, pushing or pulling the expansion of terraced land (Taradell et al., 1983; Kizos, Koulouri, 2006; Plans, 2007). But poorer peasants, marginalised from the flatter and more accessible land, have been the common predominant actors in the construction of terraces, which in the Mediterranean have historically been linked with vineyard cultivation (de Réparaz, 1990; Olarieta et al., 2008).

The investment in the maintenance of terraces was abandoned to a great extent with the changes in agricultural practices brought about by the Green Revolution mainly by the process of mechanization, as narrow terraces in particular became a burden rather than an asset. The conceptual change from a biophysical to a monetary perception of soils (Naredo, 1987) was the starting point to the neglect of stone wall terraces. The short-term perspective of this perception clashes with the long-term nature of landesque capital, and standard cost-benefit analysis simply cannot capture the rationale behind terraced landscapes (Lumley, 1997; Posthumus, De Graaff, 2005).

The abandonment of terraces is the result of the polarization of land use at all spatial scales in societies with an industrial metabolism (Olarieta, 1994), as marginal and inaccessible areas are abandoned and land use is intensified elsewhere (Olarieta et al., 2008; Cervera et al., 2015). The result is the degradation of landesque capital with frequent increases in soil erosion and a decrease in the capacity of terraces to perform their multiple functions (Koulouri, Giourga, 2007; Lesschen et al., 2008; Arnaez et al., 2011; Stanchi et al., 2012; Agnoletti et al., 2015b).

The stone walls of terraces are also significant elements in the synergies between land and human ac-

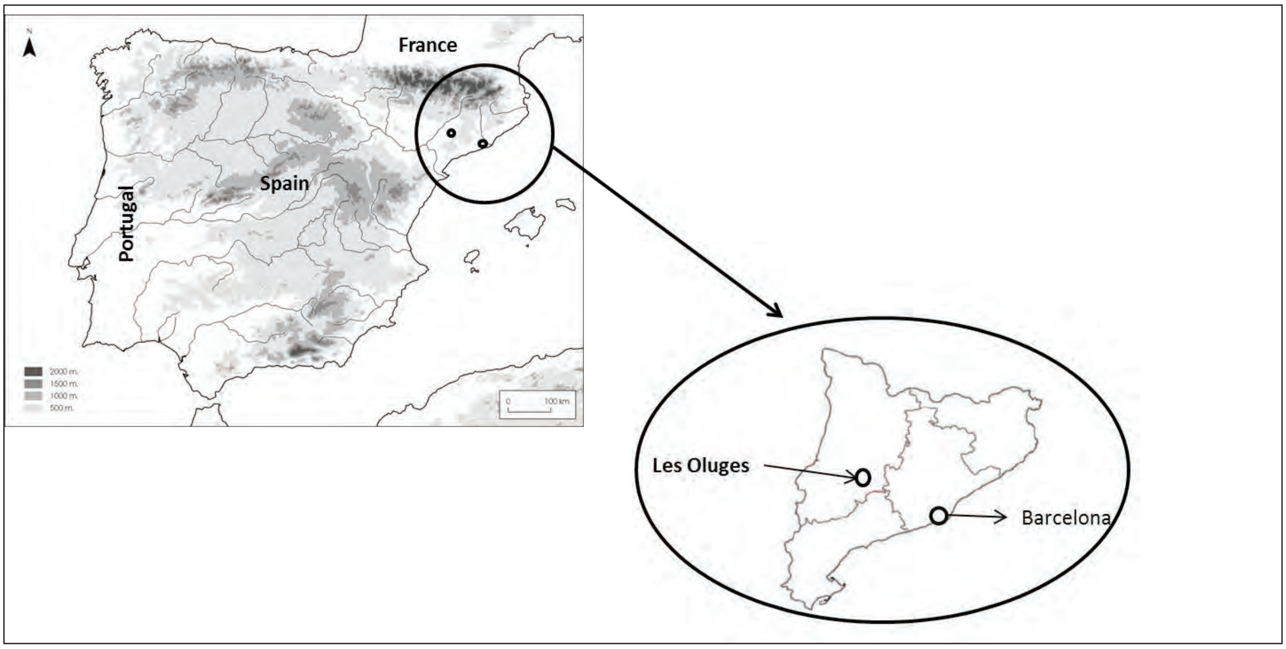

Figure 1: Location of the municipality of Les Oluges within Catalunya and Spain.

tivities. Their role as reservoirs of biological activity (Canyelles, Alomar, 2011) is very important in terms of the beta diversity of agroecosystems (Gliessmann, 2002), and contributes to the performance of agrarian systems with reduced disturbance, and therefore to strategies of 'land sharing' (Fischer et al., 2014; Tscharntke et al., 2012).

Any analysis of terrace systems should therefore include not only the interdependent but different impacts on soils, landscapes, and productive capacity, but also an ethno-historical perspective (Blanchemanche, 1990) that evaluates the labour invested and the social relations that shape them. Neglecting the analysis of agroecosystems as metabolic organisms (Ho, Ulanowicz, 2005) obliterates the past and disregards their future evolution (Antrop, 2005).

The municipality of Les Oluges has a population of 161 inhabitants, and covers 1915 ha in La Segarra (Catalunya, northeastern Spain) (Figure 1) at an altitude between 500 m and 650 m. The area has a semiarid climate, with a mean annual temperature of 13 ºC, a mean annual rainfall of 436 mm, and a mean annual reference evapotranspiration of 810 mm. In geomorphological terms, Les Oluges comprises a set of wide plateaus on limestone that fall along short slopes into the flat valley bottoms of the two streams that run through the municipality (El Sió and La Riera de Vergós). The soils are quite variable in terms of depth, and frequently have less than 50 cm on the flat hilltops while they are deeper than 150 cm on valley bottoms. They are predominantly medium-textured, have an organic matter content in the surface mineral horizon of agricultural fields of 1-2% and over 20% calcium carbonate, and a pH of 8.0-8.5.

Most of the municipality, over 80% of the land, is used for annual rainfed crops, mostly winter barley and wheat, while canola and peas are also introduced in the rotation. Barley yields are 1500 $kg.ha^{-1}$ to 3000 $kg.ha^{-1}$. Almond plantations cover 40 ha, while olive orchards occupy only 3 ha. Forests of various densities cover 200 ha, and 97 ha are covered with shrubs. The dominance of herbaceous crops is a relatively recent occurrence, as data from the late XIX shows these crops covered 35%, while forests occupied 40%, vineyards 21%, and olive orchards only 1% of the municipality (Díez, 2015).

The objective of this paper is to propose a methodology to evaluate the magnitude and conservation state of the dry-stone terrace system in the municipality of Les Oluges (Catalunya, Spain). We hypothesize that stone terraces on abandoned agricultural fields will show a poorer state of preservation than those on fields still being used.

MATERIALS AND METHODS

We studied 77 plots located on the intersections of a 500 x 500 m grid of the municipality. Each plot, 10 x 50 m in size, was located on the field with its centre on the intersection of the grid and the short side following the contour. In each plot we measured the general slope with a clinometer, and described the landform, its shape along and across the contour, and its aspect.

Plots were subdivided into individual fields if there was any change in land use or if human-made modifications of the landform, i.e., soil bunds, dry-stone terraces, or risers, divided the plot. For each field we measured its slope and length, and described its land use and surface dynamics (erosion and/or sedimentation). If soil bunds were present, we measured their height, length, and width, and processes of degradation if present.

For dry-stone walls we measured their height, length, and apparent width, and the difference in height between the surface of the upper field and the top of the wall, and described their vertical and horizontal shape, and pattern of construction. We also described the size and lithology of the rock fragments, and their surface characteristics (e.g., presence of mosses and/or lichens), and estimated the proportion of the surface occupied by empty spaces between the rock fragments. The presence of higher plants on the wall was recorded, and processes of degradation of the wall, if present, were measured.

We estimated the amount of labour required to build the stone wall system considering only a cost of one working day per 3 m^2 of wall but not the preparation activities (de Beauchamp, 1992, cited by du Guerny, Hsu, 2010). The monetary cost was calculated considering the present cost of building a dry-stone wall at 140 $euros.m^{-1}$ (Alava et al., 2009, cited by du Guerny, Hsu, 2010).

All the data were collected in a database, and the R package R (R Development Core Team, 2009) used for statistical analyses. T-tests were used to compare mean values and χ^2 tests to compare the presence of landform modifications on the various landform units, i.e., plateaus, slopes, and valley floors, and on the four main slope aspects, i.e., north, south, east, and west.

RESULTS

Five of the sampling plots (6% of the total) were completely occupied by artificial surfaces (roads, quarries, or farm buildings). In the other plots, 63% of the fields separated by modifications of the landform were used for cereal production, 58% of which were under conventional tillage and 42% under minimum tillage, and 1% for canola. Forests occupied 17% of the fields, and shrublands another 8%.

Sampling plots were mostly located on slopes (62%) and flat hilltops (21%). Among plots located on slopes, the general degree of the slope was significantly higher ($P<0.001$) in plots containing only forests or shrubland (23º, with a maximum of 40º) than in plots which only contained fields with herbaceous crops (10º, with a maximum of 19º).

There was some human-made modification of the landform, i.e., dry-stone terraces, soil bunds, or risers,

Table 1: Main characteristics of the various modifications of the landforms described in Les Oluges

	Plots1	Length2 (m)	Height3 (cm)	Width3 (cm)	Empty spaces3 (%)
Standing stone walls	23	7.6	133 (30-310)	52 (30-100)	11 (5-17)
Derelict stone walls	16	7.1	123 (30-450)	-	-
Risers	17	9.6	490 (40-1500)	-	-

1 : surveyed plots in which the modification is present.
2 : mean values per plot in which the modification is present.
3 : mean values per wall; in parentheses, the range of measured values.

in 37 plots, and stone walls were present in 23 of these (33% of the plots with an agrarian land use) (Table 1). In 7 plots two parallel stone walls were present, in 3 plots there were 3 stone walls, and one plot had a fourth wall. All these landform modifications were significantly more frequent (P=0.04) on slopes (in 62% of the plots on this type of landform) but also appeared on valley bottoms (25% of these plots) and plateaus (38%). They also appeared on all types of slopes, concave, convex, and straight, and did not show a significant preference for any slope aspect (P=0.73), as they appeared on 68% of the north-facing plots and on 50% of the south-facing plots.

Figure 2: Dry-stone wall with derelict segment (on the left) and standing segment (on the right) with three to four different patterns in the structure.

As a result of these modifications the degree of slope of the individual fields on slopes was smaller than that of the general slope previously discussed, so that the mean slope of fields with herbaceous crops located on slopes was significantly smaller (6º, with a maximum of 12º, compared to a mean general slope of 10º) (P<0.001) than that of fields with forest or shrubs (21º, compared to a mean general slope of 23º).

The stone walls followed a continuous line along the contour in all cases but one, in which the walls appeared as short segments at different positions throughout the slope. The mean length of the stone walls in the plots in which they were present was 7.6 m (Table 1). The estimated total length of standing dry-stone walls in the municipality of Les Oluges is, therefore, 86,946 m. Another 74,660 m of derelict walls are also present (Figure 2). These figures represent mean terracing intensities of 45.4 $m.ha^{-1}$, or 84.4 $m.ha^{-1}$ if the derelict walls are included.

Each wall was, in general, very homogeneous in terms of architecture. In two cases, the upper layers appeared to be more recent (i.e., with few mosses or lichens covering the rock fragments) than the lower layers of the wall. While most walls were straight vertically and horizontally, in three cases they were at an angle from the vertical following the shape of the slope. In another case, there was a narrow step running horizontally along the middle of the wall. In 19% of the cases the walls were built using outcrops of bedrock (limestone or sandstone) as foundations (Figure 3). The lithology of rock fragments was predominantly limestone, but sandstone fragments made up the lower layers in 8% of the walls. The rock fragments were placed horizontally within the wall, and had mostly a length of 30-50 cm but they reached up to 70-100 cm in either the lower or the upper layers of 25% of the walls surveyed. No completely new walls nor recent works of repair were described in the sampling plots, and no irrigation system was linked to the studied terraces, but two walls showed specific features for water drainage (Figure 3).

Considering their length, height, width, and estimated proportion of empty spaces (Table 1), the stand-

Figure 3: Stone wall built on a limestone outcrop with repaired segment on the left (notice drainage holes) and old segment on the right.

Table 2: Processes of degradation of the stone walls in relation to present land use of the plot (figures represent number of walls in which they appear; in parentheses, mean amount of soil estimated to have been removed by the process).

	Derelict	Disorganized/ bulging	Sheet erosion	Gullies	Mass movements	Piping
Herbaceous crops	10	6	1 (4.5 mm)	1 (4 mm)	4 (0.84 m3)	2 (0.48 m3)
Abandoned	10	3	3 (2 mm)	0	0	0

ing walls in Les Oluges involve 53,517 m^3, or 144,497 Mg of rock fragments. If we consider derelict walls to have similar width and proportion of empty spaces as standing walls, they add 42,500 m^3 or 114,749 Mg of rock fragments. In total, therefore, dry-stone walls in Les Oluges involve 96,000 m^3 or about 259,000 Mg of rock fragments, and would require 10 ha of a one meter-thick rock stratum as raw material.

In terms of labour, and not considering the preparation activities necessary, 38,546 working days would have been required to build the total length of walls, and in financial terms 22,540,000 euros would be required now to build the whole system of walls in Les Oluges.

Processes of degradation of the walls were frequent, including falling over of segments (derelict walls), bulging and disorganization of the structure, sheet and gully

Figure 4: Piping connected to the soil surface behind a stone wall. In the background, valley floor terraces on El Sió floodplain.

erosion of the soil behind the wall, and mass movements and piping in this soil (Table 2) (Figure 4). All processes, except for sheet erosion, were more frequent in plots presently used for agriculture than in those where agriculture has been abandoned more or less recently.

The top of the stone walls was below the surface of the upslope field in 65% of the cases (a mean difference of 57 cm), and only in one case the wall was higher than the field. Furthermore, in three cases soil sediments accumulated at the base of the wall and their volume, considering the size of the field upslope, suggested the erosion of 2-15 mm of soil (Figure 5).

DISCUSSION

The results of our survey showed a higher proportion of fields with forest and shrub vegetation (25% of the fields described within the sample plots) than the proportion of the municipality covered with these types of vegetation (16% of the municipality). Although both figures are not directly comparable, our sampling may have, therefore, underrepresented arable land. Nevertheless, we think it is a reasonable methodology to assess the extent of terrace systems.

The distribution of agricultural fields was clearly limited by the degree of slope. Even though Les Oluges has a rolling, low relief landform pattern, agriculture occupies slopes with an angle up to 19º in which the building of terraces has decreased this angle down to at most 12º. There is, therefore, a preference for placing agricultural fields on more gentle slopes. The limit value of 19º degree of slope is similar to that of 20º obtained by Tsermegas et al. (2011) in the mountainous island of Ikaria (Greece).

The terracing intensity measured in Les Oluges, 84 $m.ha^{-1}$ including derelict walls, is in the lower range of values obtained by Agnoletti et al. (2015a) in Italy, where over 400 $m.ha^{-1}$ have been described. Stone walls, although more frequent on slopes, were present on all types of landforms in Les Oluges. This suggests that creating relatively flat fields was not the sole aim of building the terraces, but also controlling surface water

Figure 5: Stone wall not reaching up to the surface of the upper field. Notice soil sediments accumulated at the base.

flows and/or minimizing processes of soil erosion. The presence of stone walls on flat valley bottoms with water streams, "valley floor terraces" according to the nomenclature proposed by Treacy and Denevan (1994), clearly points at the control of the flash floods periodically produced by these streams.

But most terraces in Les Oluges may be included in the "sloping, dry field terraces" class defined by Treacy and Denevan (1994). No braided nor pocket terraces (Lat. *sensu* Rackham, Moody, 1996) appeared in the sampling plots nor were observed in other sites. The absence of the latter type of terraces is consistent with the minimal importance of olive orchards in the municipality at least since the late XIX century, as those terraces are usually intended to support individual trees (Carbonero, 1984; Kizos, Koulouri, 2006).

In architectural terms, stone walls in Les Oluges were frequently built using rock outcrops as foundations, as has also been reported by Bevan et al. (2013) in Greece, and was encouraged in Les Oluges by the geological structure of the area, which produces rock outcrops more or less following the contour on the slopes. The stone walls of the sampling plots were apparently homogenous, with no obvious differences among the stone layers. But walls made up of various patterns of stones that may indicate different building periods (Tsermegas et al., 2011) were present in other terraces in the municipality (Figure 2). The low frequency of water drainage features, which only appeared in two stone walls (Figure 3), may be related to the relatively low rainfall in the area (436 mm), with short and intense showers of low total amount that produce much runoff but do not saturate the soil. Daily rainfall has only exceeded 50 mm four times in the past nine years, and accumulated rainfall over seven consecutive days has not exceeded 100 mm.

Many cases in the literature (e.g., Lesschen et al., 2008; Arnaez et al., 2011) have shown intense processes of degradation of both the walls and the soil associated after the abandonment of agricultural activities. But in the municipality of Les Oluges this has not been the case and the evolution of the ecosystems after abandonment has been able to check any significant degradation. In fact, degradation processes were more frequently de-

Figure 6: Stone walls built in the 1980s-1990s across a gully.

scribed on fields presently used for agriculture than on abandoned fields (Table 2).

Although no completely new walls were described in the sampling plots, a set of two twenty five meter-long walls made of concrete across a two hundred meter-long gully running through a field was observed outside the sampling plots (Figure 6). These walls were constructed sometime between 1984 and 1995 after the gully was brought into cultivation.

Modern works of repair of the stone walls were frequently observed outside the sampling plots (Figure 3) but not in them. Some walls were being repaired with dry-stone techniques; a few others had been repaired with cement; and in a few cases building garbage, including plastic material, partly filled up the soil behind the wall. Future work should assess these investments in the maintenance of landesque capital. On the other hand, some farmers acknowledge having removed some stone walls in the past in order to produce bigger and continuous fields. Similarly, some risers described in the sample plots, vertical and with a height over 10 m, may be the result of the use of heavy machinery to expand the fields.

The survey consistently showed that the upper level of the stone wall appeared below the level of the surface of the upper plot. We suggest that this may be the result of the maintenance works of the walls not keeping them up to date with the geomorphological evolution of the land surface. A possible reason for this may be the shortage of rock fragments of an adequate size, which do not appear to be frequent in the area any more. In any case, the result is that many of the dry-stone walls in Les Oluges are therefore not performing their function of controlling the overland flow of water from the upper slope, which falls over the wall as a waterfall during heavy rainfall intensity events. This has a double impact. On the one hand, soil erosion increases both on the upslope and on the downslope fields because of the increased energy of the water flow in the event of intense rainfall. And on the other, the waterfall itself

Figure 7: Segment of stone wall on the floodplain of El Sió removed by a waterfall of overland flow produced by the storm of 2nd November 2015 (c. 75 mm in 3 h). Notice the volume excavated by the waterfall at the base of the missing segment of the wall.

may excavate the base of the wall and eventually bring it down (Figure 7).

CONCLUSIONS

Dry-stone terraces are a very significant part of the agrarian landscape in Les Oluges and represent an enormous historical investment in landesque capital with obvious positive effects in terms of soil and water conservation. Degradation processes are more frequent on agricultural fields, and those stone walls that remain in place do not fulfil their hydrological function as the height of the walls is not updated to keep up with the land surface. The dialectics between degradation/removal and conservation of stone walls is falling on the side of the former with the ever-increasing size and power of machinery as the decisive factor. Therefore, institutions should consider the need for active policies to encourage stone wall preservation.

A prerequisite for this purpose is to produce systematic interdisciplinary inventories of these systems that compile their whole range of values. The sampling method proposed provides a reasonable assessment of the terrace system in relation to the effort required, even though some details may not be captured. In any case, the size of the sampling plots should be adapted to the specific location studied.

ACKNOWLEDGMENTS

This work was supported by the Social Sciences and Humanities Research Council of Canada research project SFS 895-2011-1020 and by the Spanish Government research project HAR2015-69620-C2-1-P. We would like to thank two reviewers for their helpful comments on a previous version.

NALOŽBA V KRAJINSKI KAPITAL V POLSUHIH OKOLJIH: SUHOZIDNE TERASE V LES OLUGES (LA SEGARRA, KATALONIJA)

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POVZETEK

Gradnja in vzdrževanje terasiranih krajin prestavljata obsežno naložbo v krajinski kapital, ki jo je treba utemeljiti v vsaki družbenopresnovni oceni sistemov kmetovanja. Namen tega prispevka je predlagati metodologijo, s katero bi bilo mogoče oceniti razsežnost in stanje ohranjenosti suhih zidov v terasastih sistemih. Postavili smo hipotezo, da so kamnite terase na zapuščenih kmetijskih površinah slabše ohranjene kot tiste na obdelanih površinah. Pregledali smo kamnite terase v občini Les Oluges (La Segarra, Katalonija) (1915 ha). Vzorce smo vzeli na 77 parcelah velikosti 10 x 50 m, razporejenih v mrežo na območju občine. Kmetijske površine so se pojavljale na pobočjih z do devetnajst stopinjskim naklonom, terase pa so ta naklon zmanjšale na največ 12 stopinj. Suhi zidovi so bili prisotni na 30 % vzorčenih parcel. Povprečna dolžina zidov je bila 7,6 m na parcelo, dodatnih 7,1 m pa so merile zapuščene terase. Propadanje je bilo pogostejše na kmetijskih površinah v rabi kot na terasah, zaraščenih z gozdom in grmičevjem. V 46 % primerov je bila obdelovalna površina za kamnito teraso 20–150 cm višje od vrha terase, zaradi česar je bila hidrološka funkcija terase resno ogrožena. Obstoječa mreža suhih zidov v občini Les Oluges trenutno meri približno 87 km in je sestavljena iz več kot 144.000 ton kamenja. Ta infrastruktura se zaradi različnih groženj, večinoma povezanih s kmetijsko mehanizacijo, kljub vsemu manjša, zato bi bilo treba razviti ustrezne javne politike, da bi jo ohranili.

Ključne besede: krajinski kapital, družbena presnova, konservacija prsti, erozija prsti

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