ABANDONMENT OF TRADITIONAL TERRACED LANDSCAPE: A CHANGE DETECTION APPROACH (A CASE STUDY IN COSTA VIOLA – CALABRIA, ITALY)

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Characterisation and Change-Detection of Historical Terraced Landscape

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Abstract

This paper presents the results of a change-detection study of the historical agricultural terraced landscape in 'Costa Viola' (Calabria, South Italy). During the last century, because of the loss of economic competitiveness, it has undergone progressive abandonment, followed by landscape degradation. Taking into consideration the very steep slopes of Costa Viola and the need to analyse with high precision the historical evolution of the terraced landscape, research methods were implemented coupling advanced geomatic techniques with in-situ detailed surveys. Based on historical aerial photographs, orthophotos and numeric cartography, we analysed the Land Use/Land Cover (LU/LC) change in the period 1955÷2014 using photogrammetric and geoprocessing techniques, focusing particularly on trajectories in agricultural terraces. Area covered by active terraces decreased dramatically between 1955 and 2014, from 813.25 to 118.79 ha (-85.4%). The implemented spatial database was built in a free opensource software (FOSS) taking into consideration spatial accuracies and completeness. Spatial comparison among LU/LC maps was carried out using a post-classification comparison technique that can provide complete cross-tabulation matrices. These data were compared with socio-economic statistics concerning demography and trends of farms with vineyards. The evolutionary dynamics of the active agricultural terraces were also analysed trough the definition of six types of Spatio-Temporal Patterns (STePs) recognised in the analysed period. These methods allowed to highlight the ongoing dynamics of abandonment of agricultural terraces in relation to their main causes and effects. Although tailored for the specific case study, they can be applied to many other terraced agricultural landscapes presenting similar characteristics and problems.

Keywords: Terraced landscape; Change-detection analyses; Landscape trajectories; Historical aerial photographs; Spatio-Temporal Patterns (STePs).

INTRODUCTION

In the Mediterranean basin, many rural landscapes present distinctive features descending from millennia-old agriculture. Land-use/land-cover (LU/LC) change gives a synthetic representation of that continuous interaction between the natural and cultural components from which landscapes' perceptible configuration originates (Council of Europe 2000). In historical landscapes studying LU/LC change over long time-spans is crucial not only for assessing their cultural value and integrity, but also and to set up appropriate landscape-management strategies (Antrop 2005) aiming to couple the protection of the recognized historical assets with suitable functional uses, and to justify, also from the economic point of view, their maintenance. This is particularly important in mountain areas where the two aspects converge in determining opportunities for local development strategies based on a sustainable mix of agriculture and tourism (Varotto 2008; Lasanta et al 2013; Lasanta et al 2017).

Among LU/LCs, at opposite extremes, land abandonment and soil consumption in many cases represent the main threats to landscape quality induced by human activities (Modica et al 2012; Amato et al 2016; Torre et al 2017). In this framework, the terraced agricultural landscapes appear as a case of great interest. In Europe, recent research has shown a general trend, become apparent throughout the second half of the 20th century: on the one hand, these landscapes, with their outstanding visual scenery, have progressively acquired a strong cultural and societal value, since they mark local distinctiveness and provide important landscape services (Agnoletti 2013; Tarolli et al 2014; Agnoletti et al 2015; Zoumides et al 2016); but, on the other, they have lost economic competitiveness, thus undergoing progressive abandonment, followed by either urban intrusion or spontaneous re-wilding (García-Ruiz & Lana-Renault 2011; Tarolli et al 2014; Lieskovský et al 2015). As a further consequence, the degradation of the terraced system often determines environmental hazards, particularly in areas already subject to hydro-geologic risk.

Worldwide, from 1980s up to present day, the traditional agricultural landscapes ever more have been recognised as important cultural assets requiring site-specific and diversified management strategies. Many terraced agricultural landscapes have been included in the UNESCO World Heritage List (Rössler 1993).

At a global scale, a review synthesising classification, distribution and benefits of agricultural terraces has been recently provided by Wei et al (2016). The studies carried out at a regional level recognise the need to understand the distinctive features of local terraced landscape so as to preserve landscape diversity and assess their cultural and environmental value (Romero Martín et al 2016).

Other studies, carried out at a wider scale with comparative approaches, tend to single out interregional methods and strategies to identify, monitor and manage the terraced landscapes also in the framework of specific shared programmes or initiatives (Lasanta et al 2013). In any case, most of the studies recognise that abandonment, inappropriate management and the lack of technical knowledge on them are the major problems today negatively affecting the terraced systems throughout the world (Wei et al 2016).

This paper presents the results of a change-detection approach aimed at the assessment of the historical terraced landscape of Costa Viola (Calabria, South Italy) in view of its sustainable management. Costa

Viola has been included in a first register of the Italian historical rural landscapes (Agnoletti 2013) and is one of the most representative terraced areas of the Italian peninsula, in terms both of cultural significance and total continuous area occupied. Here the agricultural terraces, with their dry-stone retaining walls, occupy very steep slopes in an area under severe hydro-geologic risk; this landscape is today recognised as worthy of protection not only because of its scenic value and its attractiveness for tourism, but also for its role in environmental protection. As in other European environments (García-Ruiz & Lana-Renault 2011), during the last century many agricultural terraces of Costa Viola have become agriculturally redundant thus undergoing progressive deterioration. Increase of environmental risk has recently raised the need to favour the permanence of terraced agriculture through a sensitive landscape management based on a precise and updated knowledge of the ongoing landscape-change dynamics.

In accordance with the findings of Tarolli et al (2015), and taking into consideration the specific geomorphological condition of the area, we carried out multitemporal spatial analysis in a GIS environment aimed to analyse with high precision the historical evolution of the terraced landscape of Costa Viola over nearly 60 years. This, at a detailed scale enabling to detect LU/LC change in conjunction with the state of maintenance of the built elements. Appropriate detection methods, coupling the use of precision tools with in-situ surveys, were needed. Moreover, a novel approach based on the definition of spatio-temporal patterns (STePs) was implemented to detect and characterise the evolution dynamics of the agricultural terraces.

MATERIALS AND METHODS

Study-area

Biophysical characteristics

Costa Viola is a coastal strip 1÷2 km large and 20 km long, located in the southern extremity of the Italian peninsula and facing the Tyrrhenian Sea (Figure 1). Costa Viola falls within the territory of five municipalities in the province of Reggio Calabria: Villa S. Giovanni, Scylla, Bagnara, Seminara and Palmi. It covers a surface of 24.1 km^2 with 0÷600 m a.s.l. altitude range and dominant N-NW aspect orientation (49.81% of the total surface). Land morphology is characterised by steep slopes (54.74% of the study-area has slope >30°) by which the Aspromonte mountain chain (literally means the “Harsh Mountain”) reaches the sea, thus forming impressive cliffs and terraces. The land presents deep and narrow valleys excavated over time by the water of the so-called *fiumare*, ephemeral streams typical of Calabria, with torrential hydrological regime and wide and flat gravel beds.

Costa Viola landscape is characterised by igneous and metamorphic rocks, while soils are subtle with acid or sub-acid reaction. Climate is Mediterranean with temperate winter and hot and drought summer with average precipitations of about 1,000 mm·year^{-1}. Moreover, frequent and intense seismic activity characterises the area. The present terraced-landscape configuration dates back to late 18th century, when the local settlements where redefined and the economic activities restarted, after the catastrophic earthquakes and tsunamis of 1783 and 1784 had totally destroyed the coastal towns in the area (Vivenzio 1788; Graziani et al 2006; Mazzanti & Bozzano 2011). Since then and up to the early 20th century, the agricultural terraces of Costa Viola were used mostly for vineyards and to a lesser extent for other crops such as olives and citrus, thus progressively conquering upwards the land before occupied by woods and wild vegetation, even in very steep sites presenting slope >70°.

Cultural aspects and values

The many artists, writers and scientists visiting Calabria since the time of the "Grand Tour", have always been impressed by the scenic value of the terraced landscape of Costa Viola, and have left beautiful and detailed descriptions of the scenery observed, thus giving an important contribution to its interpretation and cultural appreciation (Di Fazio & Modica 2008). According to UNESCO classification of cultural landscapes (UNESCO 2016), this landscape can be classified as an "organically evolved landscape" and can be included in the subcategory of *continuing landscapes*, as a landscape which has maintained "an active social role in contemporary society closely associated with the traditional way of life". Increasing awareness of cultural values can increase tourism attractiveness and counterbalance the agricultural abandonment of Costa Viola terraced landscape, mainly determined by the loss of economic competitiveness and rural depopulation, Without regular maintenance, the retaining dry stone-walls supporting the terraces rapidly decayed and lost the capacity to fully perform soil preservation (Prosdocimi et al 2016) through their important static and drainage functions, thus making the whole terraced system very vulnerable.

In order to define integrated strategies for the management of this historical rural landscape, the support of sustainable forms of agricultural land is anyway crucial. Therefore, thorough detection and interpretation of land-use change dynamics are needed, not only to better appreciate the integrity and the historical value of the present landscape, but also to offer to stakeholders and decision makers' information useful for understanding the ongoing landscape dynamics. Moreover, these data and information are useful to assess conservation/restoration actions to be discussed in stakeholders coordinating committees (Fernandes et al 2017).

Data acquisition and pre-processing

To perform all spatial analyses the following geographical base-data listed in Table I were acquired. The obtained spatio-temporal database was referred to the WGS84-UTM 33N (EPSG 32633) using the 1:5,000 numeric regional technical cartography (RTC) as geometric reference.

Table I -

The acquired historical aerial photographs for years 1955 and 1976 were digitally processed into orthophoto mosaics through Erdas photogrammetry suite (Erdas Imagine 2016). Conventional operations of image georeferentiation, orthorectification, mosaicking, co-registration and classification were performed. As reference data, we used the RTC and a set of surveyed 72 ground control points (GCPs), selected basing on the following criteria: detectable in all periods under analysis, distributed in the overlapping areas of the aerial strips (i.e., the image blocks) and easily identifiable in field (Figure 2). GCPs are crucial to establish an accurate mathematical relationship among photographs, camera characteristics, and the ground so that the exterior orientation parameters of each aerial photograph can be determined. For each GCP, ground coordinates (X,Y,Z) were collected by means of 10-minute static RTK-GNSS (real time kinematic-global navigation satellite system) surveys obtaining a planimetric accuracy of ±2.5 cm and a height accuracy of ±5 cm. In addition, to improve the overlapping of the original frames and the results of aerial triangulation, numerous tie points (e.g., points with unknown ground coordinates but visually identifiable in two or more aerial photos) were identified in each image block and automatically extracted basing on image matching techniques. The quality of the obtained tie points were checked basing on the accuracy report, deleting those with uncertainty over $3 \cdot \sigma$.

Internal and within-image orientation parameters were obtained from the camera calibration certificates for 1976 aerial photographs (average flight elevation, camera focal length, distance of fiducial marks, calculated radial lens distortion coefficient, etc.) with a classic bundle block adjustment (BA) while for those of 1955 no calibration certificates were available. In the latter case, to solve unknown camera's interior parameters we implemented a self-calibrating bundle adjustment (SCBA) procedure (Fraser 1997) based on the Brown's physical model (Brown 1971) that compensate for most linear and nonlinear forms of film and lens' distortions. As a result of the photogrammetry process, a mosaic of orthophotos was obtained for both reference years 1955 and 1976 (for more details on the implemented photogrammetry workflow see Modica et al 2014).

Land Use Land Cover (LU/LC) mapping

In producing LU/LC maps, we followed the so-called regressive photo interpretation method (e.g., Andrieu et al 2011), starting to photo-interpret from the most recent mosaic and updating it over the previous one (2014→2012→2008→1998→1989→1976→1955). For each year under analysis, a LU/LC vectorial layer was obtained and stored in a PostgreSQL-PostGIS geospatial database. To assess the thematic accuracy of LU/LC maps, a stratified random sampling was performed in 250 sampling points distributed among the various LU/LC-types according to their surface share in landscape mosaic. For evaluating user's and producer's accuracy, a confusion matrix (Congalton & Mead 1983) was applied to each of the seven LU/LC maps. Overall classification accuracy expressed with the Kappa-coefficient (Khat) varies from 0.868 (1976) to 0.995 (1998). To ensure a high level of detail, photointerpretation was carried out by the same operator at a reference scale of 1:1,000 with a minimum mapping unit (MMU) of 0.20 hectares. Moreover, prior to proceed with the change-detection analysis, the topological consistency was checked in order to eliminate sliver polygons, holes, overlap and self-intersections. To eliminate sliver polygons, those with an area <0.01 ha were merged with the biggest adjacent polygon. No holes and overlaps were found after topological check. These details allowed identification of the different categories and subcategories of the agricultural terraces. The attribute tables were built following the hierarchical scheme of CORINE Land Cover (CLC) Project (www.eea.europa.eu/publications/COR0-landcover, accessed 20 July 2017). We photo-interpreted, classified and analysed LU/LC maps according to eight LU/LC-classes (Figure 3) and 29 LU/LC-types (Figure 4), also providing an additional field to distinguish the active terraces (i.e., still cultivated) from the abandoned ones. To this end, when needed, the CLC legend was implemented at IV hierarchical level, obtaining four new LU/LC-types (2113-terraced crops; 221-terraced vineyards; 2221-terraced fruit trees; 2231-terraced olive groves) (Figure 4).

Physiographic analyses of the agricultural terraces

Physiographic analyses of the agricultural terraces (both active and abandoned) were implemented overlaying LU/LC maps with elevation, slope and aspect layers derived from a dataset of 4 co-registered digital elevation models (DEMs), all resampled at 5 m of ground sample distance (GSD) (Table I and Figure 5). The enhanced automatic terrain extraction (eATE) algorithm of Erdas photogrammetry suite was used to obtain 1955- and 1976-DEMs; contour lines and elevation points of the RTC were interpolated to derive 2008-DEM, while the 2011-DEM was extracted from aerial laser scanner (ALS) data.

To perform this analysis, the original polygonal geometries of LU/LC maps were converted into a set of points corresponding to the centre of the DEMs' pixels. Thus, each point samples an area of 25 m^2. For each reference year under analysis, descriptive statistics were calculated by means of IBM® SPSS® statistical package. The following parameters were provided: sample size (N), minimum (min), maximum (max), mean (μ), standard error of the mean (ε); standard deviation (σ); skewness (Skew), and coefficient of kurtosis (Ku) (Table IV). For the adopted formulae of Skew and Ku see Sheskin (2004).

Table II –

Table III –

Table IV -

Change-detection analysis and Spatio-Temporal Patterns (STePs) characterisation

Change-detection can be defined as a diachronic analysis allowing to identify differences in the state of an object or phenomenon observed in different time ranges (Singh 1989). It involves the application of multi-temporal datasets, to carry out a quantitative analysis of the effects, over time, of the phenomenon (Lillesand et al 2008). To avoid misregistration errors inducing false change alerts, a co-registration procedure among all the orthophoto mosaics was carried out using GCPs and the RTC as reference data. To map and quantify changes occurred for each LU/LC-class/type and to provide a complete matrix of change dynamics, we performed a post-classification comparison technique based on a thematic overlay mapping of vectorial data (Lu et al 2004). Such approach enables to determine the difference between independently classified images from each time-interval analysed (Fichera et al 2012). Where the change occurs, it is important to measure its extent, assess the spatial pattern and understand the reasons of change (Di Fazio et al 2011). In the present paper, we focus our attention on change-detection of the agricultural terraces.

We analysed the occurred LU/LC changes referring to the 8 LU/LC-classes and the 29 LU/LC-types identified, and for each time-interval considered (2014→2012; 2012→2008 2008→1998; 1998→1989; 1989→1976; 1976→1955 and the whole analysed period 2014→1955). As a result, we implemented seven 8×8 and seven 29×29 cross-tabulation matrices. For each time-interval considered, we detected the changes occurred from time t_1 to time t_2. The rows contain the values (in ha) of changes occurred for t_1 categories while the columns show the amount of changes occurred for t_2 categories. The main diagonal expresses the *persistence areas*, i.e. those areas where no changes occurred.

We also calculated the absolute and percentage change rates for each period under analysis and the average annual percentage rate of the terraced landscape where changes occurred. More precisely, we distinguished the evolution of abandoned and active terraces, as well as with specific reference to the evolution of vineyard terraces. Since the changes observed were not linear to the timeline, to calculate change rates of the terraced landscape, accordingly with other researches (e.g., Andrieu et al 2011; Di Fazio et al 2011), we adopted the single land-use dynamic degree (*r*) suggested by Puyravaud (2003). In formula:

$$r[\%] = \frac{1}{t_2 - t_1} \cdot \ln\left(\frac{A_{t_2}}{A_{t1}}\right) \cdot 100 \qquad (1)$$

where A_{t1} and A_{t2} are the areas of the considered terraces at the end and the beginning, respectively, of the period being evaluated; $t_2 - t_1$, expresses the number of years of each time-interval. All transition matrices were considered for the assessment of changes rates.

To better understand the evolution of agricultural terraced landscape of Costa Viola, we analysed its spatio-temporal dynamic (Fichera et al 2012; Modica et al 2012; Vizzari & Sigura 2015; Sun & Zhou 2016) obtaining a comprehensive view of the historic dynamics that led to its current configuration. A novel approach based on the definition of spatio-temporal patterns (STePs) was implemented to detect and characterise the evolution dynamics of active agricultural terraces. Each LU/LC map was converted in a 1m x 1m raster format, assigning the value ‘1’ to active terraces and ‘0’ for all other LU/LC classes. All seven raster maps were then overlaid with combinational OR procedure (i.e., assign a new number to each unique combination of input data), thus obtaining a comprehensive matrix of the occurred changes. From the theoretical 128 combinations (2^n, where $n = 7$ expresses the number of investigated years), a total of 73 change trajectories were detected, synthesised and mapped according to the following 6 STePs (Figure 6):

1) Permanent Terraced Agricultural Areas (P-TrAg): pixels presenting value 1 in all investigated years;

2) Abandoned Terraced Agricultural Areas (A-TrAg): pixels with 1 as starting value (1955) and for which only one change trajectory, i.e. from 1 to 0, was detected;
3) Increased Terraced Agricultural Areas (I-TrAg): pixels with 0 as starting value (1955) and for which only one change trajectory, i.e. from 0 to 1, was detected;
4) Temporary Abandoned Terraced Agricultural Areas (T-TrAg): pixels for those two changes were detected, from 1 as starting value (1955) to 0 (in one or more intermediate years) and again to 1 as ending value (2014);
5) Temporary Increased Terraced Agricultural Areas (TI-TrAg): pixels for which two changes were detected, from 0 as starting value (1955) to 1 (in one or more intermediate years) and again to 0 as ending value (2014);
6) Floating Terraced Agricultural Areas (F-TrAg): pixels for which at least 3 change trajectories were detected.

RESULTS AND DISCUSSION

Accuracy of the photogrammetric process

Significant desk and fieldwork were required to select and survey all GCPs, also considering the morphology and the continuous landscape changes recorded in the study-area in the last decades. The accuracy of bundle block adjustment (BA) procedures mostly depends on the number and distribution of GCPs in the overlapping area of each image-block, especially in areas characterised by steep slopes as in our case, and when no camera calibration certificates are available, as in the case of 1955 aerial photographs. Moreover, these aerial photographs were acquired by Fairchild SF 295 camera and had no corner fiducial marks. That said, if the number and the distribution of GCPs are satisfactory, also the different SCBA method has a lesser influence on achieving a good accuracy (Aguilar et al 2013). A summary of aerial triangulation results for the image blocks involved in this study is given in Table II. While all 72 GCPs were utilised for 1976 aerial photographs, a total of 25 GCPs fulfil the above mentioned criteria in the case of 1955 aerial photographs. A minimum of 7 GCPs were employed in each image block. Moreover, after a quality check, 168 and 580 tie points were used in 1955 and 1976 image blocks, respectively. Actually, just 10 of them were deleted because fallen in floating parts of coastline. The total image unit-weight root mean square error (TIUW RMSE), which describes the overall precision of the GCPs measurements on the aerial photographs, ranges from 4.577 to 6.154 pixels in 1955 and from 0.786 to 2.505 pixels in 1976 image blocks. Analysing X,Y residuals it can be noticed how mean values are always less than 0.35 m. Z residuals are within 0.61 m. Actually, the analysis of σ of residuals denotes a certain degree of variability but their values are always less than 2 m. As expected, greater values of TIUW and X,Y,Z residuals were found for 1955 image blocks and for those covering portions of study-area with higher slope changes.

Planar and vertical accuracy of the extracted DEMs were quantified using RMSE statistic and using GCPs as reference. Planar/vertical RMSE was 0.5/2.75 m for 1955 and 0.35/2.35 for 1976.

Considering the accuracy results of the BA procedures and the morphology of the study-area, the obtained accuracy was very satisfactory.

Evolutionary trends of the agricultural terraced landscape of Costa Viola

The overall transition matrix shows a strong decrease of the active agricultural terraces in the analysed time-span (1955÷2014) (Table III). The same picture emerges analysing the landscape composition for all considered time-intervals based on transition matrices and according to the 8 LU/LC-classes (Figure 3A). Between 1955 and 2014, the area occupied by active terraces decreased from 813.25 ha to 118.79 ha (-85.4%, r=-3.26). The highest loss degree rate has been recorded in the time interval 1989÷1998, r=-5.14, when the active terraced area decreased from 302.59 ha to 190.44 ha (-37.06%).

Referring to the LU/LCs-types, and focusing on agricultural terraces, in 2014 79.37 ha (66.8% of active terraced area) are covered by vineyards (CLC 2211), while 29.06 ha (24.46%) by olive groves (CLC 2231), 8.63 ha (7.26%) by fruit trees (CLC 2221) and 1.70 ha (1.4%) by crops (CLC 2113). In the investigated period, the surface covered by terraced vineyards, the most representative crops in the study area, decreased dramatically, from 708.14 ha in 1955 to 79.37 ha in 2014 (-88.79%, r=-3.71) (Figure 3B). The most part of this surface loss is due to the abandonment of agricultural practices that determined the transition to the potential forest communities, which gradually occupied these areas.

Analysing in detail, 282.82 ha have changed from terraced vineyards (CLC 2211) to terraced transitional areas (CLC 3241), 77.61 ha to terraced Mediterranean sclerophyllous wood (CLC 323), 25.45 ha to terraced sparsely vegetated areas (CLC 3331) and 4.07 ha to terraced high tree woodlands (CLC 3111 and 3114). Moreover, it was not possible to photo-interpret 92.39 ha of the 'terraced' surfaces due to the growing up of forest vegetation, and the dry-stone walls collapse following the abandonment. These surfaces are currently characterised by Mediterranean sclerophyllous wood, oak and chestnut formations (CLC 323, 3111 and 3114, respectively). Other significant dynamics that determined loss of terraced vineyards are linked to soil sealing. The following transformations occurred: 22.01 ha to human settlements (CLC 111 and 112); 16.27 ha to commercial and services areas (CLC 121, 141 and 142); 14.42 ha to roads and infrastructures (CLC 122) mainly due to the construction, in years between 1964 and 1972, of the A3 Salerno–Reggio Calabria motorway, and highlighted in the time-interval 1955÷1976. Moreover, another important change direction linked to the presence of A3 motorway concerns the transformation of terraced vineyards into construction sites (CLC 133) in two different periods: the first one during the building of the motorway (time interval before year 1976), the second one during its subsequent modernisation (2007÷2016) and influencing the three time-intervals after 1998.

Focusing on terraced fruit trees (CLC 2221), it is important to highlight two main subsequent steps of their shrinking due to the urban settlements expansion, and mainly located in Scylla municipality and in Marinella area (Bagnara municipality). The first one in the time-interval 1955÷1976, with a loss of 10.14 ha (r=-0.86), and the second one in 1989÷1998 time-interval with a loss of 11.55 ha (r=-3.48). Urban expansion cannot be justified by demographic reasons, since in the same period population decreased and aged. In fact, as reported by the Italian national institute of statistic (ISTAT, http://demo.istat.it/index_e.html, accessed 15 July 2017) the total inhabitants of Scylla and Bagnara municipalities decreased from 20,735 in 1951 to 16,674 in 1998 and to 15,418 in 2015 (-24.13%). Moreover, in the last four decades, a significant increase of population aged ≥ 65 can be highlighted (+50.45%), from 2,208 in 1985 (12.90% of residents) to 3,322 in 2015 (21.55% of residents).

Concerning the decrease of terraced olive groves (CLC 2231), it must be noticed how this change is partly balanced by a land use transformation from terraced vineyards to terraced olive groves. We also analysed the dynamics of terraced crops (CLC 2113) that, actually, cover very small surfaces and represent a secondary income for farmers that juxtapose this LU/LC to other more profitable terraced cultivations. Hence, it is interesting to notice how for this LU/LC the analysis of transition matrix shows no persistence areas in the main diagonal.

Analysing the spatial configuration of agricultural terraces with reference to elevation it is possible to highlight two different trends, the first concerning the active terraces, the second the abandoned terraced areas. Agricultural terraces at higher elevations are those interested by olive groves (CLC 2231). However, their mean elevation decreases from 1955 (523.12 m, ε=0.76) to 2014 (442.57, ε=0.76). At the intermediate elevation range (∼200 m a.s.l.), Costa Viola landscape is characterised by the terraced vineyards (CLC 2211). During the analysed period, we registered a concentration around the mean, the value of which changes from 216.76 m (ε=0.22) in 1955 to 232.51 m (ε=0.58) in 2014 (max 590.23 m in 1955, 421.90 m in 2014). As expected, the abandoned terraces located in the higher part of the study-area, gradually have been regained by forest formations including forestry plantations (i.e., chestnut woodlands in the higher areas). Focusing on active terraces, it is interesting to notice how the steeper areas are occupied by terraced vineyards, with a decrease of mean slope from 27.50° (ε=0.02) in 1955 to 18.76° (ε=0.55) in 2014. The other three types of "active terraced", in each year of the time-series investigated, cover areas characterised by a mean slope less than 15° (15.44° in 2008 with ε=0.17 for terraced fruit trees) with maximum peaks of above 50° (54° in 1998 for terraced olive groves).

Aspect seems not be significant in the localisation of the still active terraced areas because they are not located with a recognisable scheme, actually reflecting the aspect direction distribution of the Costa Viola landscape.

The analysis of STePs improves the characterisation of landscape change trajectories, giving a comprehensive picture of the historical evolution of active terraces, also highlighting past and ongoing change trajectories. As described in the methodological section, 73 of the 128 theoretical combinations have been detected and then synthesised in 6 STeP types. Prior to analyse the surface distribution within each STeP, it is important to consider that the total surface interested by agricultural terraces in the investigated period, thus covered by one of the defined 6 STeP-types accounts for 859.92 ha (35.6% of the whole study area). This surface is greater than the above described LU/LC TrAg class (813.25 ha in 1955) considering that it takes into account floating, increased and abandoned terraced areas after 1955. The widest surface belongs to the A-TrAg type (abandoned terraces), 679.95 ha. Moreover, permanent terraces (P-TrAg) only concern 7.74% of the surface covered by STePs, most of them falling in the Bagnara municipality. Only 0.73% of the entire STePs covered area, and composed of very small patches, falls in the I-TrAg type (i.e., new active terraces compared to the starting year, 1955). STePs' analysis shows strong evidence of the difficulties linked to the permanence of active agricultural terraces in Costa Viola. In this respect, it is interesting to notice how 40.33 ha of the current active terraces fall in the TA-TrAg type; in other words, these active surfaces in 1955 had been abandoned at least one time during the investigated period. On the other hand, 35.53 ha were not active in 1955, restored during the observation period and currently abandoned, thus classified as TI-TrAg. Finally, the F-TrAg is type which comprises surfaces for those at least three changes (active ⇆ abandoned) were recorded and accounts for 31.32 ha.

The ongoing abandonment of the terraced vineyards of Costa Viola

The abandonment of the agricultural terraces in the Costa Viola landscape confirms the more general trend of viticulture decline at municipal and regional level, clearly described by the data on vineyards cultivation extracted from the agricultural general censuses conducted by ISTAT (www.istat.it/en/agricultural-census, accessed 24 July 2017), for years 1970, 1982, 1990, 2000 and 2010. Farms with vineyards dramatically decreased from 1970 to 2010, from 373 to 32 (-91.42%) and from 524 to 27 (-94.85%) in Scylla and Bagnara municipalities, respectively. This trend reached the highest magnitude in the last inter-census decade (2000-2010) with a decrease of more than 75%.

As expected, and as highlighted for several significant terraced areas (Arnáez et al 2015), in the Costa Viola landscape, the abandoned terraced vineyards are those which are too far from road infrastructures and are characterised by higher slopes. In fact, the abandonment occurred firstly in those areas steeper than 30° and not easily accessible because of their distance from the main roads. Overlaying current active terraces to public roads network reveals distance to roads as a major driver in the ongoing abandonment: while in 2012 all active terraces were within 300 m, in 2014 this value dropped to 200 m.

Moreover, overlaying active terraces with cadastral map, the parcel fragmentation emerges dramatically. We superimposed the latest free available cadastral map (year 2011) with active terraces extracted from 2012 LU/LC map: active terraces fall in 2,479 cadastral parcels, and only 7 of them with a surface >1 ha (μ=0.05, ε=0.004). Active terraced vineyards fall in 2,084 cadastral parcels and only 1 of them with a surface >1 ha (μ=0.04, ε=0.001).

CONCLUSIONS

As in other European landscapes, the traditional terraced viticulture of Costa Viola is now considered as “heroic agriculture”, once made possible by a number of converging factors: farms operated by large families with significant availability of young agricultural workforce; long-term land-rental contracts, favouring investments in land amelioration; sufficient competitiveness of non-mechanized agriculture; favourable local wine-market; humble lifestyles tolerating hard work in the fields; awareness of the dependence from the place and passionate sense of care for it. Today most of those factors have weakened or disappeared. The present decline of terraced viticulture finds its main reasons in: general abandonment of agriculture; decline of agricultural employment; ageing of rural population; further fragmentation of land property, already high, as a consequence of heritage transmission; increase of labour cost and of its relative share of the total production cost; loss of competitiveness of small farms and labour-intense agriculture; delays in the definition of policies and actions to support agriculture in the terraced areas.

The work carried out offers a comprehensive picture of the terraced landscape evolutionary trends, covering nearly sixty years and highlighting the ongoing dynamics of abandonment in relation to their main causes and effects. Despite of the policies of valorisation implemented up to now and the recognition of their cultural and environmental values, agricultural terraces are still subject to a continuous abandonment that is more relevant in those ones less accessible and more difficult to cultivate. Here, with the spontaneous re-naturalisation wild vegetation has regained little by little the space it once occupied.

The need to support the permanence of terraced agriculture claims for a sensitive landscape management based on a precise and updated knowledge of the landscape system. In this direction, the spatial database implemented in our research provides a highly detailed level of information, both geometrically and temporally, allowing spatial querying at different scales. It also can be easily combined with socio-economic data, representing a useful tool in the sustainable planning and management of the historical terraced landscape. Although tailored for Costa Viola, the method implemented can have a more general application in the many other terraced areas presenting similar characteristics and problems. Moreover, the data and information produced can constitute a reference base in implementing risk management plans.

An open issue still is the need of an accurate assessment and monitoring of the state of dry-stone walls in order to single out recovery actions for the abandoned terraces. Some farmers, like heroes of agricultural preservation, still cultivate terraced plots thus keeping their environmental functions. They need to be encouraged and supported by means of tailored agro-environmental measures.

Actually, as highlighted by Kizos & Koulouri (2010), to be more effective, these preserving measures should push farmers to adopt environmental practices. In the near past, to help the maintenance and recovery of dry-stone walls and terraced plots, specific measures were allocated in the Rural Development Programme (RDP) 2007-2013 for Calabria, some of which have been re-proposed in the RDP 2014-2020. To achieve public financial help a minimum plot surface of 1 ha is required. That limit drops to 0.3 ha for owners participating in farmers’ cooperatives. Considering the above highlighted high fragmentation of the terraced areas, in 2004 it was established the cooperative “Enopolis Costa Viola” that brings together 60 farmers and since 2006 produces the “Armacìa” TGI (typical geographic indication) wine. These cooperative efforts contributed significantly in reducing the abandonment of terraced vineyards considering that from 2004 to 2014 they were restored a total of 4500 m^3 of dry-stone walls, interesting an area of 40 ha of terraces at risk of abandonment. Further widespread cooperative approaches are needed; moreover, the sharing of information among the many partners involved is crucial for the definition of adequate landscape-management strategies. These last should be based on the necessary integration between: the maintenance of sustainable agricultural uses of the terraced system, and the full valorisation of the many eco-system services it can today offer, particularly those concerning rural tourism and recreation.

ACKNOWLEDGEMENTS

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Figure Legends

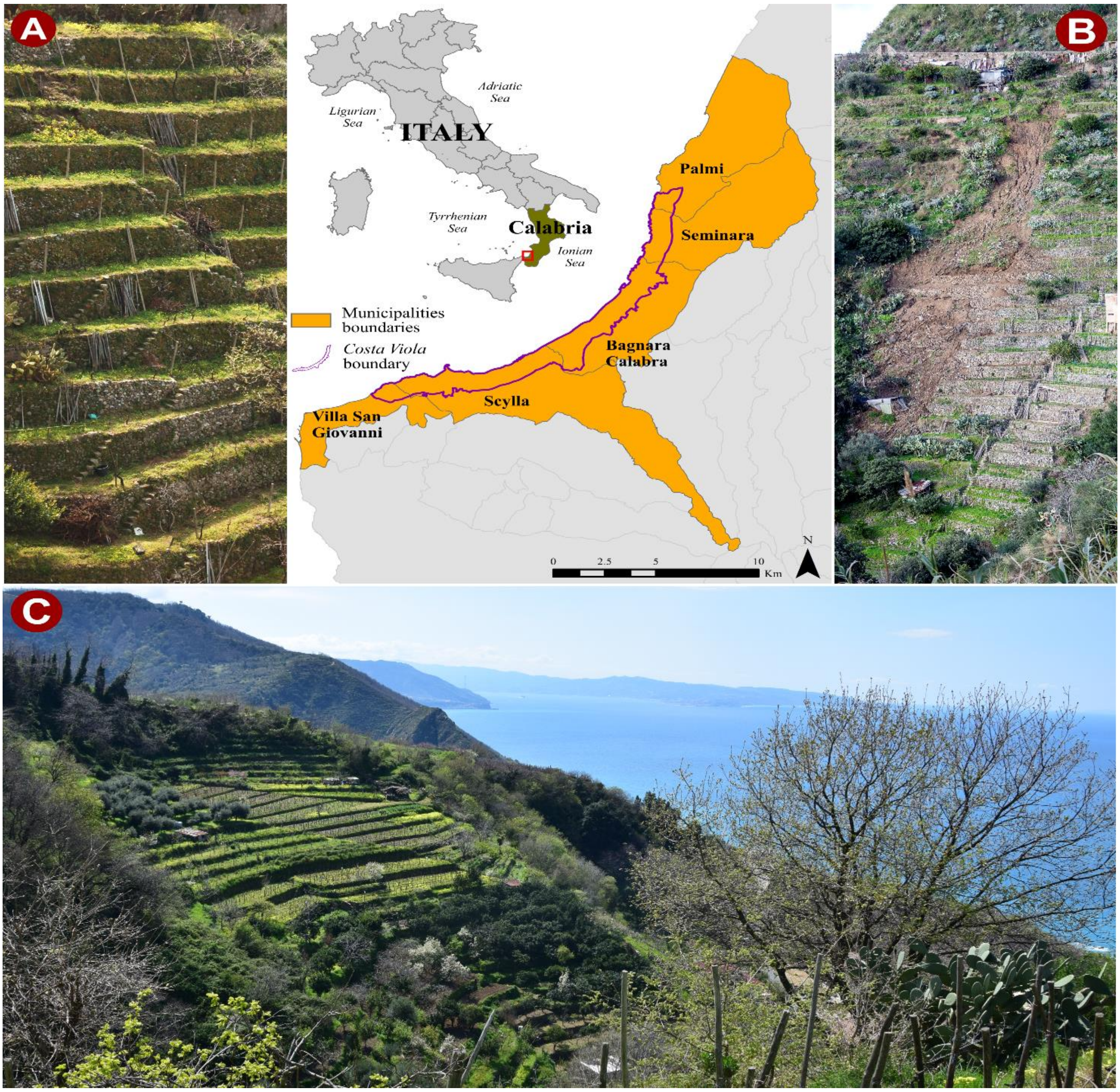


Fig. 1 – Geographical localisation of the study-area, *Costa Viola*. Example of the traditional cultivated agricultural terraced landscape of Costa Viola characterised by dry-stone retaining walls (A); a recent shallow landslide (December 2015) with the initiation point located in an abandoned terrace and interesting a cultivated one (B); panoramic view of a typical terraced area (C).

Fig. 2 – Four illustrative examples of ground control points (GCPs): a1-d1), as they were surveyed on the field; a2-d2), in the 2014 RGB orthomosaic; a3-d3) and a4-d4) in 1976 and 1955, respectively, aerial photographs.

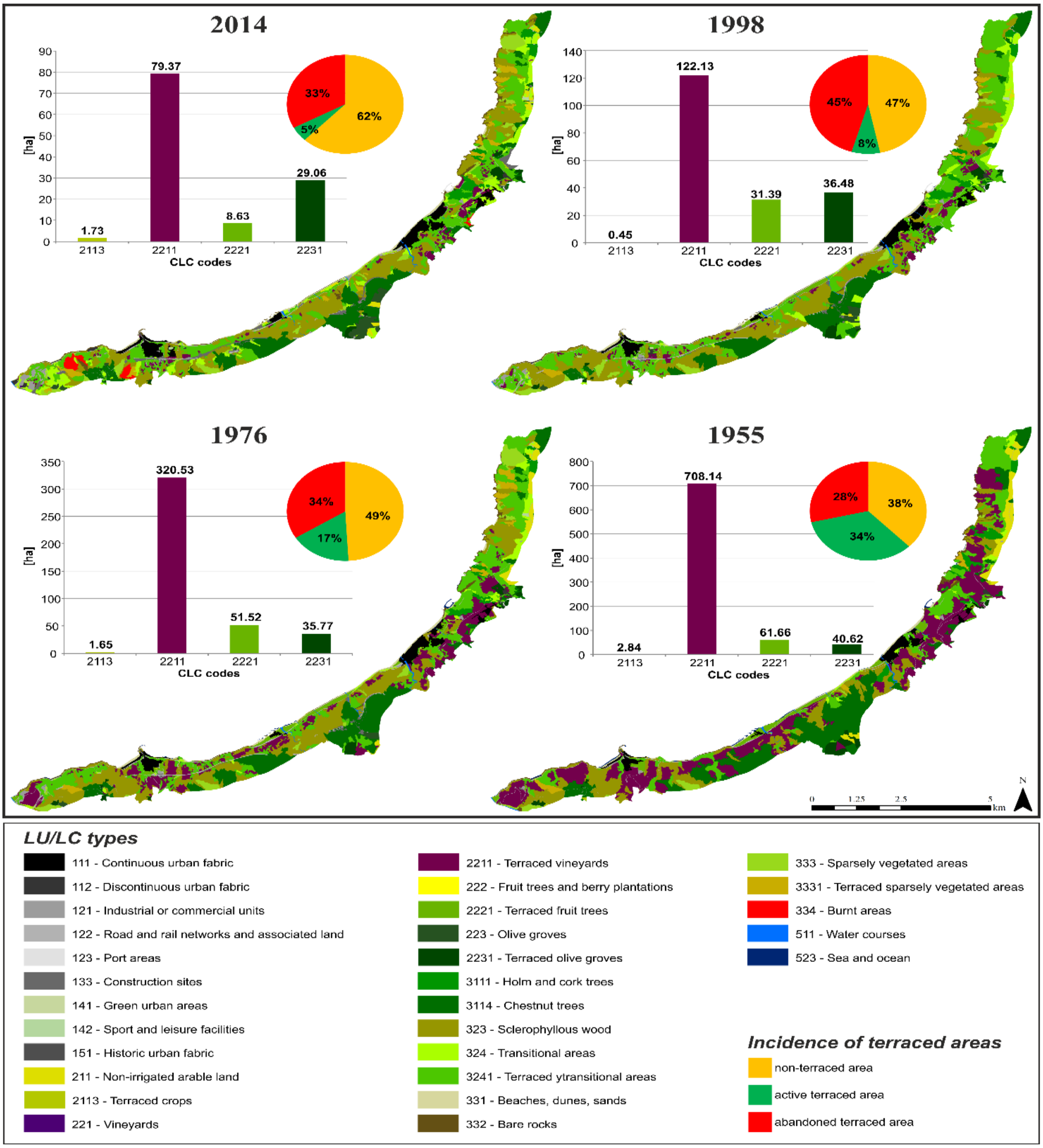
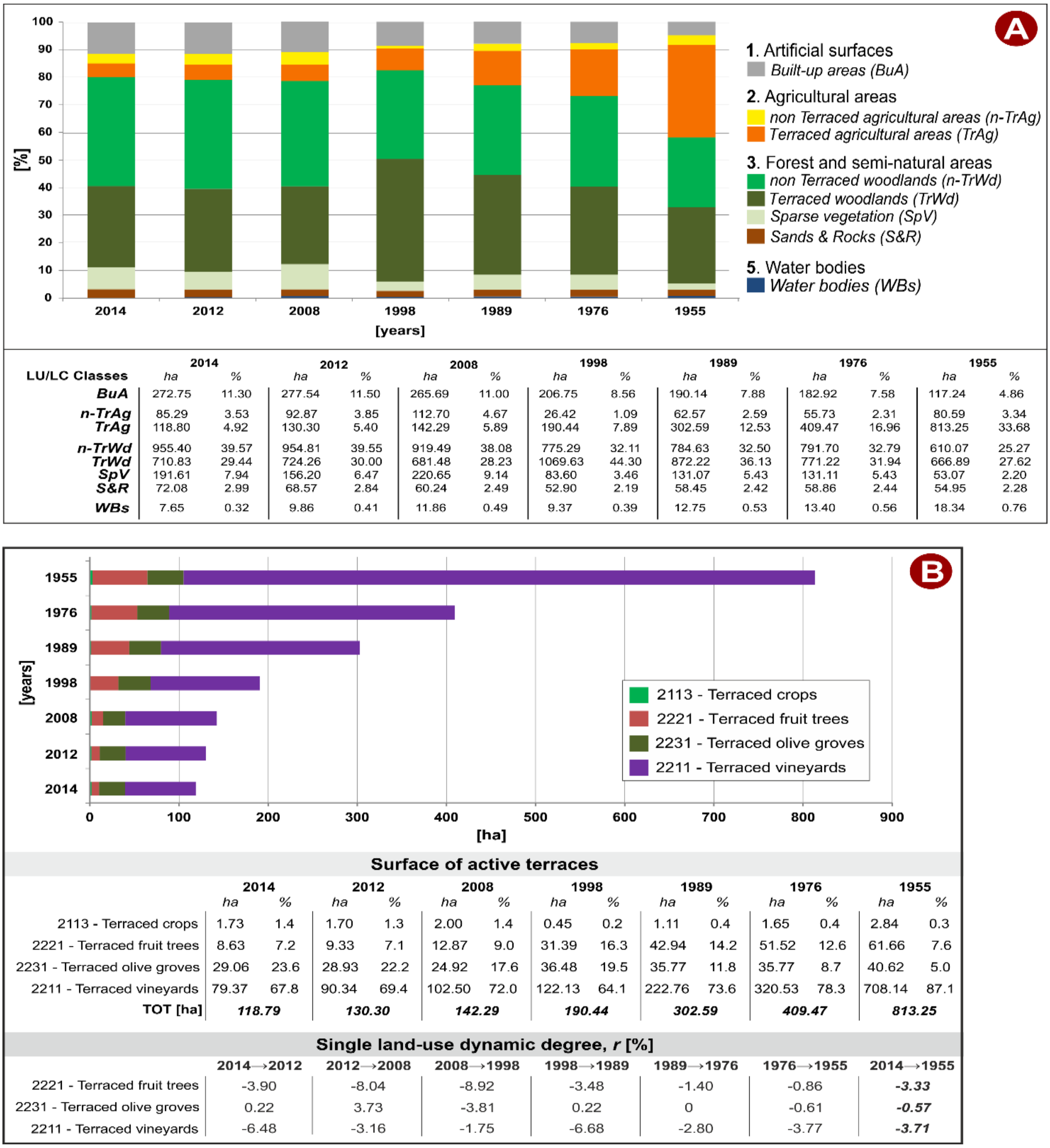


Fig. 3 – Land Use/Land Cover (LU/LC) maps for the reference years 2014, 1998, 1976, and 1955. For each map, the detail of landscape composition referring to the incidence of terraced areas (pie charts) and the surface of agricultural terraces (histogram charts) was provided.



LU/LC Classes	2014		2012		2008		1998		1989		1976		1955	
	ha	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*
BuA	272.75	11.30	277.54	11.50	265.69	11.00	206.75	8.56	190.14	7.88	182.92	7.58	117.24	4.86
n-TrAg	85.29	3.53	92.87	3.85	112.70	4.67	26.42	1.09	62.57	2.59	55.73	2.31	80.59	3.34
TrAg	118.80	4.92	130.30	5.40	142.29	5.89	190.44	7.89	302.59	12.53	409.47	16.96	813.25	33.68
n-TrWd	955.40	39.57	954.81	39.55	919.49	38.08	775.29	32.11	784.63	32.50	791.70	32.79	610.07	25.27
TrWd	710.83	29.44	724.26	30.00	681.48	28.23	1069.63	44.30	872.22	36.13	771.22	31.94	666.89	27.62
SpV	191.61	7.94	156.20	6.47	220.65	9.14	83.60	3.46	131.07	5.43	131.11	5.43	53.07	2.20
S&R	72.08	2.99	68.57	2.84	60.24	2.49	52.90	2.19	58.45	2.42	58.86	2.44	54.95	2.28
WBs	7.65	0.32	9.86	0.41	11.86	0.49	9.37	0.39	12.75	0.53	13.40	0.56	18.34	0.76

Surface of active terraces

	2014		2012		2008		1998		1989		1976		1955	
	ha	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*
2113 - Terraced crops	1.73	1.4	1.70	1.3	2.00	1.4	0.45	0.2	1.11	0.4	1.65	0.4	2.84	0.3
2221 - Terraced fruit trees	8.63	7.2	9.33	7.1	12.87	9.0	31.39	16.3	42.94	14.2	51.52	12.6	61.66	7.6
2231 - Terraced olive groves	29.06	23.6	28.93	22.2	24.92	17.6	36.48	19.5	35.77	11.8	35.77	8.7	40.62	5.0
2211 - Terraced vineyards	79.37	67.8	90.34	69.4	102.50	72.0	122.13	64.1	222.76	73.6	320.53	78.3	708.14	87.1
TOT [ha]	***118.79***		***130.30***		***142.29***		***190.44***		***302.59***		***409.47***		***813.25***	

Single land-use dynamic degree, *r* [%]

	2014→2012	2012→2008	2008→1998	1998→1989	1989→1976	1976→1955	2014→1955
2221 - Terraced fruit trees	-3.90	-8.04	-8.92	-3.48	-1.40	-0.86	***-3.33***
2231 - Terraced olive groves	0.22	3.73	-3.81	0.22	0	-0.61	***-0.57***
2211 - Terraced vineyards	-6.48	-3.16	-1.75	-6.68	-2.80	-3.77	***-3.71***

Fig. 4 – Landscape composition of the study area in the seven time-span intervals investigated from 1955 to 2014, according to the main 9 landscape classes (A) and to the 4 classes of active terraces (B). The single land-use dynamic degree (r) is also provided for the main active terraces.

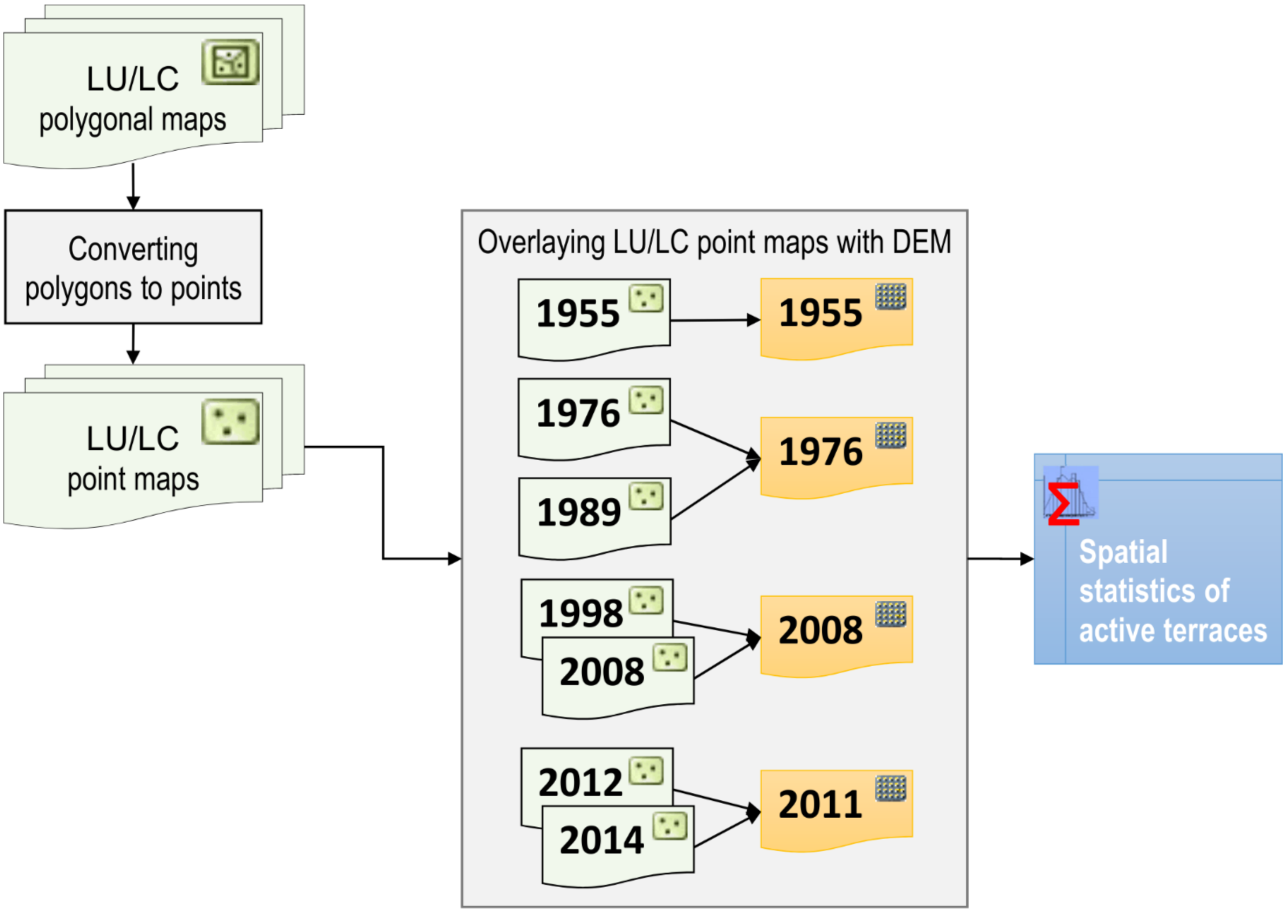
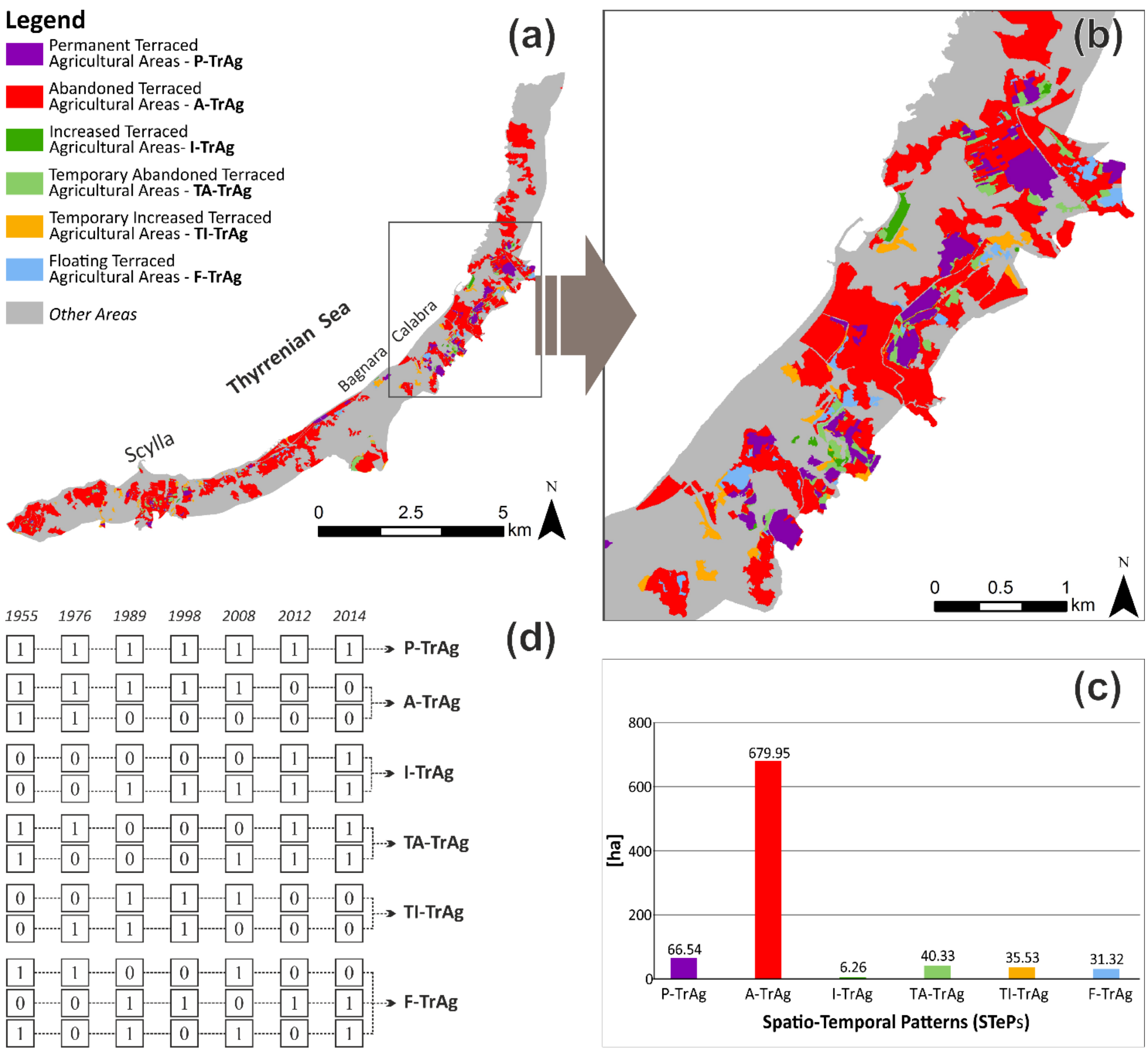


Fig. 5 – Flow-chart showing the physiographic analysis process.



1955	1976	1989	1998	2008	2012	2014	
1	1	1	1	1	1	1	P-TrAg
1	1	1	1	1	0	0	A-TrAg
1	1	0	0	0	0	0	
0	0	0	0	0	1	1	I-TrAg
0	0	1	1	1	1	1	
1	1	0	0	0	1	1	TA-TrAg
1	0	0	0	1	1	1	
0	0	1	1	1	0	0	TI-TrAg
0	1	1	1	0	0	0	
1	1	0	0	1	0	0	F-TrAg
0	0	1	1	0	1	1	
1	0	1	0	1	0	1	

Fig. 6 – Spatio-Temporal Patterns (STePs) of the Agricultural terraces of Costa Viola in the investigated period (1955÷2014). (A) The whole picture of the study-area; (B), a magnified detail of the area belonging to the municipality of Bagnara Calabra, in which most part of agricultural terraces fallen; (C) a set of exemplificative trajectories leading to the six types of STePs; (D) a graph showing surface distribution according to the defined STePs – data in [ha] and [%].

Tables

Table I

Frame data	Year	Ground sample distance (GSD) [m]	Source
B/W aerial photos (average elevation flight 6,000 m a.s.l.) scanned at 2,500 dpi	1955	0.35*	Italian Military Geographical Institute (IGMI)
B/W aerial photos (average elevation flight 2700 m a.s.l.) scanned at 800 dpi	1976	0.45*	
B/W digital aerial orthophotos	1989	1	WMS service exposed by National GeoPortal of the Italian Ministry of the Environment, Land and Sea (www.pcn.minambiente.it/GN/en/accesso-ai-servizi-eng/wms-display-service)
RGB digital aerial orthophotos	1998	1	Acquired through the Cartographic centre of the Calabria Region (CCR)
RGB digital aerial orthophotos	2008	0.5	Cartographic centre of the Calabria Region
	2012		Agency for Agricultural Payments of the Calabria Region (ARCEA)
RGB digital orthophoto-mosaic	2014	0.5	Pansharpened and orthorectified WorldView-2 imagery
Regional technical numeric cartography (RTC), nominal scale 1:5,000	2008	---	Cartographic centre of the Calabria Region (CCR)
Vectorial cadastral map	2011	---	
Digital elevation models (DEMs)	1955	2.5**	Automatic extraction trough photogrammetry process
	1976	2.5**	Automatic extraction trough photogrammetry process
	2008	5	Obtained interpolating contour lines and elevation points of the RTC (planar/vertical accuracy ±0.15/1.2 m)
	2011	1**	Aerial laser scanner (ALS) data provided by Italian Ministry for Environment, Land and Sea (planar/vertical accuracy ±0.15/0.3 m)

* The obtained ortho-mosaics were resampled with a GSD of 0.5 m

** All digital elevation models were resampled to 5 m of GSD; accuracies were assessed using the X,Y,Z coordinates of GCPs and expressed as RMSE.

Table II

Year	**n. strips**	**ID strip**	**n. aerial photographs**	**n. GCPs**[a]	**TIUW RMSE**[b] **[pixel]**	**Mean residuals [m]**			**Standard deviation (σ) [m]**		
						X	*Y*	*Z*	*X*	*Y*	*Z*
1955	3	254-230	2	8	6.154	0.1675	0.3460	0.6140	0.7033	1.4720	1.8630
		254-231	2	7	1.425	0.0251	0.0085	0.0726	0.1117	0.0296	0.2652
		254-232A	3	10	4.577	0.3420	0.2880	0.5480	1.5090	1.3330	2.1320
1976	9	254-1	3	9	1.995	0.0761	0.0526	0.2980	0.3616	0.2455	0.8210
		254-2	4	7	2.027	0.1687	0.1421	0.0917	0.6873	0.6198	0.3835
		254-3	3	11	1.643	0.1396	0.1206	0.2282	0.4683	0.3913	0.5441
		254-4	7	13	2.505	0.1509	0.3120	0.1962	0.6723	1.3180	0.9362
		254-6	3	8	2.188	0.0289	0.0001	0.1253	0.1872	0.0001	0.8489
		254-10	4	10	0.786	0.1524	0.2050	0.1486	0.9164	1.3590	0.6666
		254-11	3	10	1.842	0.2870	0.3430	0.2160	1.5630	1.7100	0.6460
		254-12	3	9	0.923	0.2440	0.2410	0.0728	1.5280	1.6370	0.3418
		245-30	3	7	2.178	0.0620	0.1790	0.2980	0.3507	0.5880	0.8450

[a] GCPs: ground control points.

[b] TIUW RMSE: total image unit-weight root mean square error; it represents the total RMSE for the triangulation, i.e. a global precision indicator describing the quality of the entire bundle block adjustment (BA.

Table III

LU/LC Classes	BuA	n-TrAg	TrAg	n-TrWd	TrWd	SpV	S&R	WBs	**TOT**
BuA	**115.11**	0.04	0.16	0.43	1.42	0.00	0.00	0.08	117.24
n-TrAg	11.07	**22.17**	0.01	46.72	0.62	0.00	0.00	0.00	80.59
TrAg	101.44	38.03	**108.18**	140.40	374.96	43.05	6.82	0.37	813.25
n-TrWd	20.01	21.11	1.73	**487.12**	32.87	34.16	12.38	0.70	610.07
TrWd	15.49	3.84	8.68	271.55	**291.25**	69.64	6.44	0.00	666.89
SpV	2.61	0.00	0.00	3.65	5.62	**41.13**	0.06	0.00	53.07
S&R	4.18	0.10	0.04	4.77	3.96	3.61	**38.28**	0.00	54.95
WBs	2.83	0.00	0.00	0.76	0.13	0.00	8.11	**6.50**	18.34
TOT	272.75	85.29	118.81	955.40	710.84	191.59	72.08	7.65	**2414.41**

Table IV

Year	**Topographic stratum**	**CLC code**	**N**	**Min**	**Max**	μ	ε	σ	**Skew**	**Ku**
2014	*Elevation [m]*	2113	697	306.20	485.32	405.80	3.04	80.39	-0.25	1.91
		2211	31739	4.38	421.90	232.51	0.58	104.07	-0.44	-0.97
		2221	3453	2.31	290.20	79.36	1.61	94.96	0.96	-0.48
		2231	11574	340.35	588.90	442.57	0.76	82.17	0.65	-0.15
	Slope [°]	2113	697	0.19	29.66	12.52	0.23	6.13	0.58	-0.03
		2211	31739	0.33	54.95	18.76	0.55	9.76	0.51	-0.48
		2221	3453	0.10	47.09	14.14	0.20	12.08	0.78	-0.69
		2231	11574	0.60	45.54	12.22	0.66	7.12	1.20	1.30
2012	*Elevation [m]*	2113	686	306.20	485.32	407.15	3.07	80.32	-0.29	-1.89
		2211	36093	4.81	421.90	221.15	0.56	106.64	-0.22	-1.17
		2221	3727	2.31	290.20	81.94	1.52	98.78	0.87	-0.53
		2231	11510	340.35	588.90	441.89	0.76	81.89	0.67	-1.15
	Slope [°]	2113	686	0.19	29.66	12.47	0.23	6.15	0.60	-0.02
		2211	36093	0.33	54.95	20.02	0.05	10.41	0.43	-0.70
		2221	3727	0.10	47.07	14.07	0.19	11.81	0.78	-0.60
		2231	11510	0.06	45.54	12.23	0.66	1.13	1.20	1.29
2008	*Elevation [m]*	2113	795	306.83	485.32	411.75	2.36	66.53	-0.20	-1.64
		2211	40984	3.21	422.61	211.96	0.55	111.27	-0.13	-1.30
		2221	5133	1.65	290.20	66.03	1.20	86.39	1.26	0.27
		2231	9868	163.51	569.40	409.42	0.55	54.70	0.66	2.04
	Slope [°]	2113	795	3.65	29.66	13.23	0.18	5.22	-0.28	0.19
		2211	40984	0.19	54.95	20.34	0.52	10.61	0.39	0.78
		2221	5133	0.10	49.54	15.55	0.17	12.33	0.64	-0.82
		2231	9868	0.06	45.54	12.83	0.08	7.55	1.04	0.65
1998	*Elevation [m]*	2113	178	561.28	564.85	565.00	0.14	1.90	0.34	-0.77
		2211	45540	4.97	458.60	229.09	0.52	110.34	-0.12	-1.35
		2221	12067	0.52	282.71	25.60	0.39	43.12	2.68	8.51
		2231	14607	304.10	597.49	465.78	0.86	103.75	-0.21	-1.73
	Slope [°]	2113	178	5.13	20.98	11.44	0.28	3.74	0.35	-0.53
		2211	45540	0.06	60.22	19.64	0.50	10.61	0.49	-0.70
		2221	12067	0.03	48.32	9.93	0.08	9.31	1.26	0.64
		2231	14607	0.03	54.00	10.53	0.05	6.60	1.36	2.37
1989	*Elevation [m]*	2113	435	7.83	599.32	401.03	13.12	275.96	-0.72	-1.49
		2211	89014	4.97	600.21	256.66	0.41	123.38	0.37	0.16
		2221	17227	0.25	273.80	27.32	0.35	46.19	2.56	6.72
		2231	14248	306.41	591.95	457.42	0.81	97.04	0.10	-1.56
	Slope [°]	2113	435	0.11	19.14	6.45	0.21	4.52	0.45	-0.93
		2211	89014	0.03	60.13	19.86	0.37	11.21	0.41	-0.84
		2221	17227	0.01	48.32	10.00	0.07	9.56	1.26	0.77
		2231	14248	0.06	40.76	11.56	0.55	6.64	0.97	0.73
1976	*Elevation [m]*	2113	651	7.83	599.33	293.33	10.72	273.47	0.15	-1.91
		2211	128107	4.78	600.21	220.82	0.35	124.81	0.62	-0.20
		2221	21061	0.33	273.80	36.82	0.36	52.06	1.73	2.33
		2231	14248	306.41	591.95	457.2	0.81	97.05	0.10	-1.56
	Slope [°]	2113	651	0.11	21.17	5.97	0.16	4.07	0.77	-0.01
		2211	128107	0.03	67.00	22.31	0.03	12.48	0.25	-1.01
		2221	21061	0.01	49.75	11.77	0.77	11.20	1.22	0.57
		2231	14248	0.56	40.76	11.56	0.55	6.64	0.97	0.73
1955	*Elevation [m]*	2113	1148	337.46	532.30	464.93	2.03	109.81	0.10	-0.95
		2211	282880	0.48	590.23	216.76	0.22	118.99	0.39	-0.69
		2221	24394	0.00	205.98	25.65	0.27	42.13	-1.35	0.01
		2231	16205	305.31	597.65	523.12	0.76	97.33	-1.35	0.02
	Slope [°]	2113	1148	1.45	30.96	8.78	0.13	4.29	2.69	8.73
		2211	282880	0.06	70.67	27.50	0.02	12.80	-0.17	-0.87
		2221	24394	0.01	49.61	8.01	0.05	7.90	1.69	2.63
		2231	16205	0.06	40.76	9.12	0.04	5.73	1.31	2.34