Using historical maps to analyze two hundred years of land cover changes: Case study of Sorrento peninsula (south Italy)

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Stefania Pindozzi[a], Elena Cervelli[a], Alessandra Capolupo[a], Collins Okello[a,b] and Lorenzo Boccia[a]

[a]Department of Agricultural Science, University of Naples Federico II, Via Università 100, Portici, NA 80055, Italy; [b]Department of Biosystems Engineering, Gulu University, P.O. Box 166, Gulu, Uganda

ABSTRACT

Historical maps are effective sources of geographical information and useful for historical and territorial research. In this study, the examination of landscape dynamics on the basis of historical maps over a period of more than 200 years was conducted. The study area is Sorrento peninsula and part of the near Sarno river basin in South Italy. This study provides a general framework for the assessment of the overall quality and accuracy of historical maps. The application of the methodology used in this specific case study can contribute to a better understanding of the dynamics of the landscape in the long term. The derived knowledge can be applied in the planning of the landscape in order to implement correct conservation strategies. The comparison was made on four maps 1817, 1875, 1960, and 2006. Geodetic accuracy of the sheet maps of 1817 and 1875 offer a right basis for a macro analysis of land cover dynamics, evaluating conversion from one land cover category to another. Main trans- formation, identified in the period between 1875 and 1960, was the disappearance of vineyards, which covered 25% of the total study area in 1875. Agricultural areas increased in this period to cover 57% of the total area.

KEYWORDS
Land use cover change; historical GIS; Sorrento Peninsula; MapAnalyst; kappa statistic

Introduction

Several studies have demonstrated the importance of landscapes history in landscape planning and manage- ment (Marcucci 2000; Antrop 2005). Knowledge of the past could influence people's preferences in con- serving the current landscape (Hanley et al. 2009). Currently, the most commonly used method for ana- lyzing the dynamics of landscapes involve comparison of land cover maps derived from remotely sensed (RS) data. Use of remote sensing techniques poses intrinsic limitations on the benchmark for the comparison of land use and land cover change (LUCC). It is well documented that human activities have transformed the earth's environment over the past 300 years, espe- cially through conversion of natural ecosystems to agriculture (Ramankutty and Foley 1999). Extensive analyses of land use history are therefore required (Foster 1992; Foster, Motzkin, and Slater 1998) by prolonging the period of observations with historical maps, when available (Börjeson 2009). Historical maps are effective sources of geographical informa- tion (Bitelli, Cremonini, and Gatta 2014) and useful for historical and territorial research (Brovelli and Minghini 2012). Studies on land use change over long periods of time are very important in ecology (Rhemtulla, Mladenoff, and Clayton 2007) and help to link human activity with ecosystem changes (Foster 1992). Nevertheless few land use change studies over more than 100 years are reported, because of scarcity of good historical data sources (Rhemtulla, Mladenoff, and Clayton 2007).

Certainly, not every map was produced with the intent of accurate representation of the reality but in some cases, with military or propagandistic purpose. Hence, for a correct use of old maps for historical research, it is necessary the evaluation of accuracy and reliability of their information content after the geore- ferencing process (Jenny and Hurni 2011). During the nineteenth century the level of accuracy and reliability of maps, due to geodetic survey, was finally attained in many European countries as a consequence of the gen- eral achievements in cartographic techniques (Konvitz 1983; Cesnulevicius and Beconyte 2006; Galambos and Timár 2008; Podobnikar 2009; Chías and Abad 2009, 2010; Kovács and Timár 2010; Heere 2011; Branch 2011). After the assessment of reliability and accuracy of historical maps, it is possible to conduct qualitative and quantitative studies to assess, among others, histor- ical land use (Jenny and Hurni 2011).

During the last 10 years, the use of geographical information system (GIS) in historical research has seen a growth of interest. The contribution of historical GIS is related to the possibility of performing qualita- tive and quantitative analysis of changes over time (Gregory and Healey 2007).

The present work documents the LUCCs over the past 200 years in Sorrento peninsula and parts of the Sarno river basin, which is located in Campania region of southern Italy. The area is considered to be a tradi- tional agrarian landscape, meaning that it was low in technological advancement prior to the period of industrialization and has preserved many ancient fea- tures (Calvo-Iglesias, Fra-Paleo, and Diaz-Varela 2009). The Sarno river basin and Sorrento peninsula is known as one of the most important local tourist systems in the Mediterranean region (Carli 2012) with important heritage that has to be protected (Fabbricatti and Oppido 2010). It is also famous for its traditionally terraced agrarian landscape mostly cropped with lemon trees and a variety of agricultural products such as lemon liqueur, mozzarella cheese, and pasta. However, LUCC over this important agricultural and tourism landscape is not well understood and documented.

The purpose of this study was to assess the magni- tude, rate, and direction of change in land cover in the study area using historical maps of 1817 and 1875, together with more recent images of 1960 and 2006. Specifically, the objective was also the valuation of the evolution of urban sprawl within the Sarno river basin and Sorrento peninsula. Furthermore, this study pro- vides a general framework for the assessment of the overall quality and accuracy of historical maps that is necessary before their use in any application (Menzano-Agugliaro et al. 2014).

Materials and methods

Study area

Delimiting the boundaries of the study area can be done according to several methods depending on the purpose of the study itself (Skaloš and Engstová 2010). Map sheets of 1875 overlay only a part of the total area covered by the map sheets of the other time steps analyzed. Hence, in this study, the boundaries were delimited on the basis of the map sheets of 1875 that covered a section of the Sarno river basin and the Sorrento peninsula of southern Italy (Figure 1). The area comprises 15 municipalities and covers an area of about 100 km^2. The elevation ranges from sea level to about 867 masl (meters above sea level) with a mean of 400 masl. The mean annual temperature and pre- cipitation are 16.3°C and 1036 mm, respectively. The area is dominated by agricultural land, with few set- tlements on the hills while the majority of the popula- tion live at the coastline, which is highly urbanized. The current land cover is typically predominated by olive trees and lemon groves. Mixed deciduous cop- piced woods and a few chestnut trees can be found in the lowlands (Fabricatti and Oppido 2010; Tagliafierro et al. 2013). The area also has a plain of tertiary deposits, surrounded by mountain of carbonate rocks impermeable complex. Areas with the lowest elevation along the peninsula are comprised of marls and clays (PTR 2008).

Map data sources and processing

Land cover data have been derived for the time steps of 1817, 1875, 1960, and 2006. The main characteris- tics and sources of maps used in the study are described in Table 1.

Data sources

Historical cartography consists of ancient cartographic documents, and in many cases they are not exposed to the public, even if they are of great historical and geographical value (Bitelli, Cremonini, and Gatta 2014). Seven historical maps sheets were used in this study, two of which were of 1817, four maps of 1875, and one of them was of 1960 (Table 1).

Since the middle of the fifteenth century in the kingdom of Naples, conditions favorable to the devel- opment of a cartography that historians indicate as “modern” and modern techniques for territorial and geographical surveying were created (Valerio 2007). The effectiveness of the cartographic sources used in this study for landscape analysis is related to their historical land use data content. Both maps of 1817 and 1875 were realized based on geodetic survey. They clearly report symbolism to indicate crops and land divisions, leading to a big improvement in comprehen- sion of the real use of land in the past.

The maps of the year 1817 (Figure 2) were drawn during the period when the kingdom of the two Sicilies controlled the area. They were drawn by the officers of the Royal Topographic Office under the direction of Ferdinando Visconti (1772–1847). It followed the first geodetic survey in France around 1680 (Konvitz 1983), which inspired other nations to establish national map surveys. The office was established by Joachim Murat, in 1814 during Napoleonic era, and was derived from the *Regia Officina Geografica* from which the first car- tographic service of the state for both civil and military

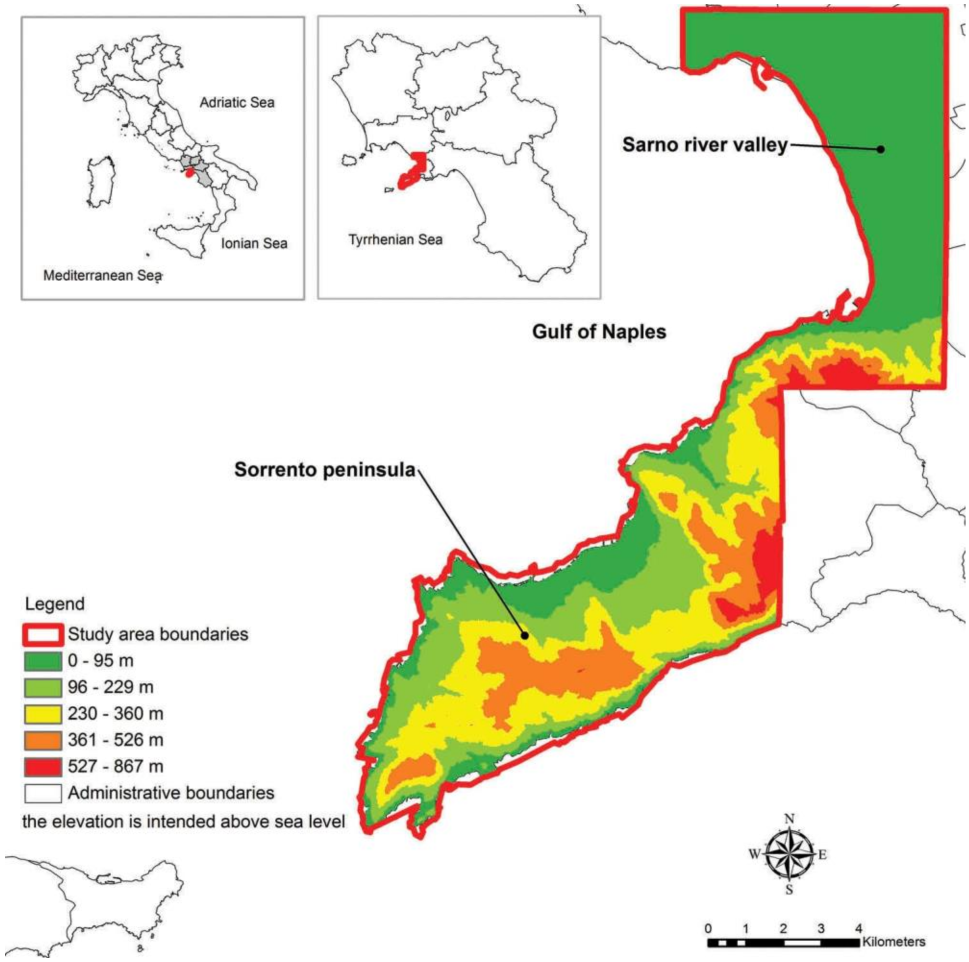

Figure 1. Map showing the location and outline of the study area.

purposes originated. The map was of very high quality and won awards as the best cartographic product of the continent at the Universal Exhibition in London in 1851 (Galluccio 2007). The map is accurate in topo- graphic features and gives a reliable picture of Neapolitan Kingdom during the French decade (1806–1815) (Galluccio 2007). Land use is indicated mainly by toponymy, symbolism of crops and land (Zannoni and Principe 1993).

The maps of 1875 (Figure 3) were produced by the Italian Military Geographic Institute (IGM), and con- stitutes the basis of the cartography of the Italian state. Symbolism of the legends of topographic maps created by IGM has remained almost unchanged since 1861, the year of its foundation. Tree crops, bushy shrubs, and the woodlands are characterized by species and density. The same applies to the representation of the different forms of infrastructures such as settlement systems, industrial and handicraft production areas, road networks, railway lines, as well as mining and quarrying land, and the different forms of energy use. The consistency of representation over the years allow for the evaluation of land use of Italian territories in both quantitative and qualitative terms (Vianello 2004). The maps of the first two dates, with the detailed view of areas covered by main categories analyzed, are reported in Figures 2 and 3.

The 1960 TCI/CNR map was produced in 1960 by the Centre for Studies in Economic Geography of the National Research Council and the Italian Touring Club. It was the first document on land cover produced at a national scale using information derived from cartographic surveys and site visits. Land use was derived from cartographic survey initially mapped on a scale of 1:2000, 1:1000, or 1:1500. This map generally designated land use classes but for the purpose of this study, it has to be intended as land cover map (Pelorosso, Leone, and Boccia 2009).

The main characteristics and sources of maps used in the study are described in Table 1.

Data processing and georeferencing

The hard copy maps were digitized into TIFF at a resolution of 300 dpi. The raster data were then

Table 1. Main characteristics and sources of maps used for the time series reconstruction.

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Map title	Sheets number	Data source	Printed	Scale	Origin	Map format and processing results	Land use/cover vector file name
Topographic and hydrographic contour map of Naples edited by ROT	12, 15	Field Survey 1816–1817	1817–1819	1:25,000	Courtesy of "Biblioteca di Area Architettura," University of Naples Federico II	Raster file, 96 dpi	LU1817
Topographic map of Mount Vesuvius, Torre Annunziata, and Castellamare di Stabia edited by IGM	14, 15	Field Survey 1871–1876	1875–1876	1:10,000	Italian Military Geographic Institute	Raster file, 300 dpi	LU1875
Map of Italy (Punta Orlando, Vico Equense) edited by IGM	184 II SE, 196 I NE	Field Survey 1875–1876	1900	1:25,000	Courtesy of Department of Agriculture, University of Naples Federico II	Hard copy, scanned at 300 dpi	LU1875
Land-Use Map of Italy edited by TCI/CNR	16	Field Survey 1960		1:120,000	Courtesy of "Nucleo Bibliotecario di Geografia," University of Naples Federico II	Hard copy, scanned at 300 dpi	LU1960
CORINE Land-Cover CLC2006, third level		Satellite images 2006 ± 1 year		1:100,000 minimum unit interpreted 25 ha	Available from SINAnet CORINE Land cover Project I and CLC2006	Vector file	LC2006

Note: ROT, Regia Officina Topografica di Napoli (Royal Topographic Office); IGM, Istituto Geografico Militare Italiano (Italian Military Geographic Institute); TCI/CNR, Touring Club Italiano/Centro Nazionale Ricerche (Italian Touring Club/National Research Center); SINAnet, Rete del Sistema Informativo Nazionale Ambientale-ISPRA (Network of National Environmental Information System).

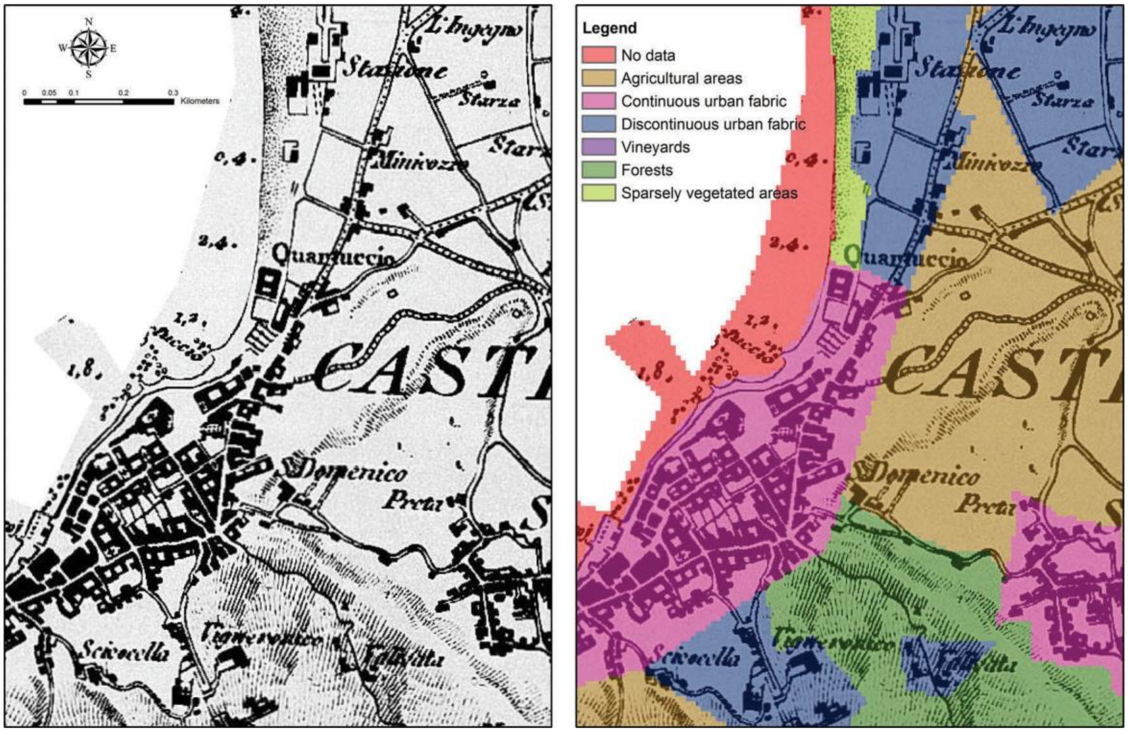

Figure 2. Detailed view of a portion of the original map on the *left* and the corresponding raster classification of the same area on the *right* in 1817.

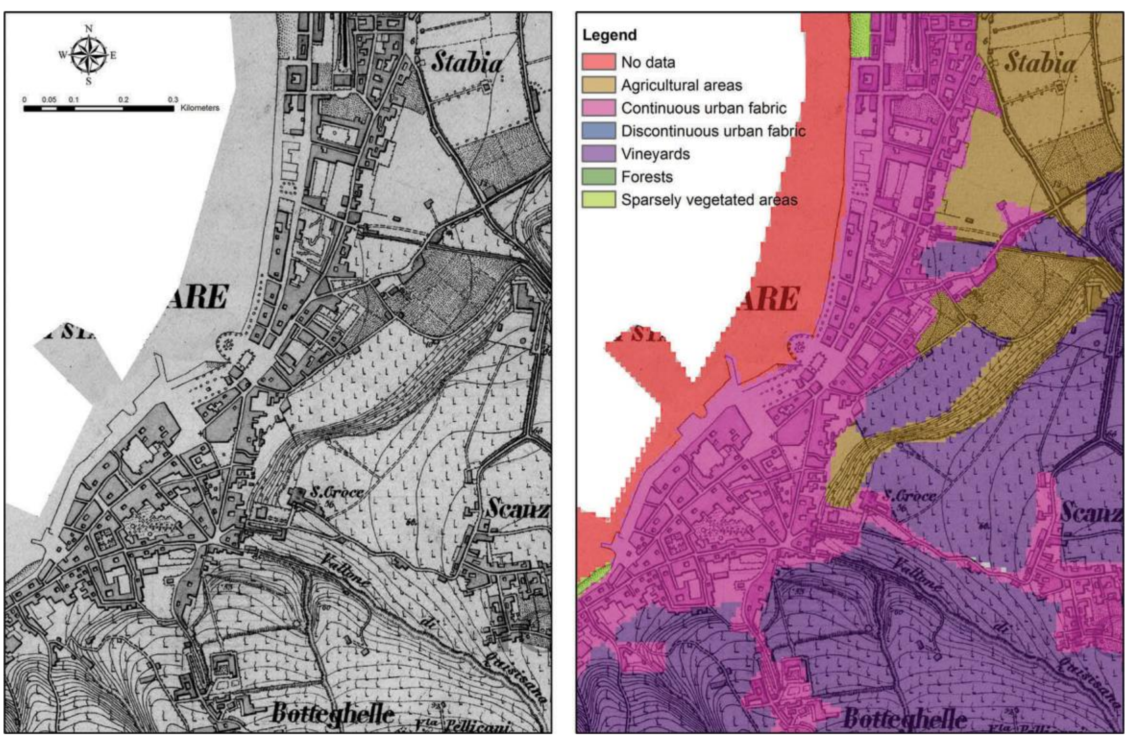

Figure 3. Detailed view of a portion of the original map on the *left* and the corresponding raster classification of the same area on the *right* in 1875.

imported into ESRI® ArcMap 10.0 software and geor- eferencing toolset was used in accordance with Lafreniere and Rivet (2010). The georeferencing pro- cess results in a coordinate transformation algorithm, which links the digitized historical map to the current reference projection system (UTM-WGS84, zone
33 N). A first order polynomial was generally used for the transformations. The quality of the georeferen- cing process was evaluated by overlapping the histor- ical map with the current Regional Technical Map (CTR) of Campania region with a scale of 1:5000. When the root mean square (RMS) value was over 100 m, an attempt was made to reduce it using the second order polynomial (Brovelli and Minghini 2012). Links between the digitized historical map and the current reference and projection systems were made on the basis of the correspondence of ground control points (GCPs) obtained from the CTR of Campania region on a scale of 1:5000. The number of GCPs used was high enough to achieve a satisfactory level of transformation accuracy. After the georeferencing pro- cess, historical maps of the same years were processed to remove grid reference on the boundary with Adobe Photoshop® CS6 and then patched together to create a mosaic with the Mosaic tool of ArcMap 10.0.

Visual accuracy of the historical maps of 1817 and 1875 has been assessed with the help of MapAnalyst, an open source Java application (Jenny and Hurni 2011). MapAnalyst calculates the mean position error (MPE) and the standard deviation (SD), that is, the mean deviation error, for all the control points on the old maps. The lower the MPE and the SD are, the more accurate the old map is (Podobnikar 2009).

Time series of land use/cover and land cover map

Land use/cover was derived from map sheets of the years 1817 and 1875, and from the 1960 TCI/CNR map, which contained land cover information. A review of relevant literature on the history of the study area was carried out to verify the information interpreted from the old maps. These supplementary data were used to verify quantity of land occupation for the different land cover classes. Particular attention was paid to the cadastral data of Murat period reported by Scarpa (2012). From other studies, information about wine and wheat consumption as well as the main processing industries has been obtained (Cantone 2013; Tino 1993; Mangone 1976). The land cover units were distinguished visually according to the land cover type. Vector files containing land cover data were derived by visual interpretation and subsequent manual classification (Lautenbach et al. 2011) with the aid of auxiliary sources (Skaloš and Engstová 2010). The procedure for manual vectorization, known as vectorising, is most widely used because it can ensure a particularly high precision, if performed accurately. Much depends on the ability of the operator who must be able to recognize and interpret points directly on the image. The procedure was conducted by visually recog- nizing entities and rebuilding polygons directly on the raster image, through definition of points while oper- ating in ArcMap 10.0 (Gatta 2010). Vectorising was done with ArcMap 10.0 software after the georeferen- cing process.

Meanings of symbols used and cartographic repre- sentation of the historical maps were described by Mori (1990). Mixed land use classes were assigned to the class of vineyards when the corresponding symbol was found and to agricultural land in the other cases. Missing data were neglected.

After the landscape elements were digitized in accor- dance with the classification system, their area and peri- meter were calculated in the database table for each polygon. Current land cover class was derived from CORINE land cover (CLC) map of 2006 (ISPRA 2010). The map of 1817 was considered as the reference map, that is, the map is considered as baseline for LUCC analysis.

Thematic generalization

Each map reported different land use/cover categories, and some categories did not appear in some of the maps. In order to carry out a direct comparison of paired land cover maps, it was necessary to apply thematic general- ization (Petit and Lambin 2002; Rhemtulla, Mladenoff, and Clayton 2007; Pelorosso, Leone, and Boccia 2009). The original 18 items of CLC and 21 items of TCI/CNR were merged into 7 common classes that are the land use categories reported on the reference map of 1817. The seven classes were agricultural areas, continuous urban fabric, discontinuous urban fabric, vineyards, forests, sparsely vegetated areas, and no data. The use of no data class was necessary to perform the comparison as it will be explained in the next section. The area studied constitutes a peninsula whose boundaries are subject to a big change over the years due, for example, to the build- ing up of harbors or to the reduction of the shoreline. This class was called no data because it refers to an area that exists on the map of a given year, but it does not exist on one or on all the three remaining time steps analyzed. The decision of not merging the vineyards class with the agricultural areas class was made in order retain information about vineyards that was reported with a clear symbolism on the first map of 1817. Reclassification of legends of CLC level 3 and of the

Table 2. Classification of the seven land cover classes including class description of 1817 and 1875 maps.

Category name	CLC level 3	TCI/CNR 1960	IGM 1875, ROT 1817
Continuous urban fabric	1.2.1 Industrial or commercial units 1.2.3 Port areas 1.4.2 Sport and leisure facilities 1.1.1 Continuous urban fabric	Built-up areas and other uses	Continuous built-up areas, it includes residential built-up areas as well as various technical structures, yards, warehouses, car parks, etc. as well as buildings it also includes other built-up surfaces excluding land transport system[a]
Discontinuous urban fabric	1.1.2 Discontinuous urban fabric	Built-up areas and other uses	Most of the land is covered by structures; buildings, roads, and artificially surfaced areas are associated with vegetated areas and bare soils, which occupy discontinuous but significant surfaces[b]
Agricultural use	2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation	–	Agricultural land utilized as arable land; it includes both, large, intensively utilized agricultural fields and small croft-type fields; the category also includes fruit groves, gardens, and other productive green surfaces[a]
	2.4.1 Annual crops associated with permanent crops	Non-irrigated annual crops associated with trees	
	2.2.2 Fruit trees and berry plantations	Orchards, citrus groves, olive groves, vineyards mixed with olive groves	
	2.1.1 Non-irrigated arable land	Non-irrigated arable land	
	2.1.2 Permanently irrigated land	Irrigated arable land	
	2.4.2 Complex cultivation patterns	Vineyards mixed with olive groves	
	2.2.3 Olive groves	Olive groves	
Vineyards	2.2.1 Vineyards	Vineyards	Areas planted with vines[b]
Sparsely vegetated areas	2.3.1 Pastures 3.2.1 Natural grasslands 3.3.3 Sparsely vegetated areas 3.3.2 Bare rocks	Pasture and uncultivated productive even if partially or temporarily used for arable crops, Barren land	Sparsely vegetated and unstable areas of stones, boulders, or rubble on steep slopes with vegetated layer[b]
Forests	3.2.4 Transitional woodland-shrub 3.2.3 Sclerophyllous vegetation 3.1.1 Broad-leaved forest 3.1.3 Mixed forest	Coppice, high trunk wood	Growths composed of various kinds of wood species regardless of their functions as forest, connected green, or scattered green in open landscape; wood vegetation within town residential area was not included into this category[a]
No data	This class considers coastal shoreline variations. It is the results of the difference between the polygon obtained from the merge of all vectorial land use maps and each original vectorial land use map		

Notes: CLC, CORINE land cover; TCI/CNR, Touring Club Italiano/Centro Nazionale Ricerche; IGM, Italian Military Geographic Institute; ROT, Regia Officina Topografica di Napoli.
[a]Skaloš et al. (2011).
[b]European Topic Centre on Spatial Information and Analysis (Eionet).

1960 map is reported in Table 2, which also gives descrip- tions of the classes of the 1817 and 1875 maps.

Land cover change detection and cross-tabulation methodology

Comparison of successive paired land use/cover maps was performed using the freeware Map Comparison Kit (MCK) developed by the Research Institute for Knowledge Systems (RIKS) in Maastricht, the Netherlands (Visser and De Nijs 2006; Hewitt and Escobar 2011). To accomplish the comparison with the MCK software, it is necessary that all land use maps are equal in size. Since the study area is a peninsula, there was the problem of coastal shoreline variations. The solution was to create a “no data” class in each land use map as a result of the difference between the polygons obtained by merging and dissolving all vectorial land use maps together and the previous land use map. Polygons subtraction was performed with the Model Builder of ArcMap 10.0. The resulting no-data polygon was then added to each land use map. All the geoprocessing opera- tions were performed in ArcMap 10.0.

Second, vectorial files of land use were transformed in raster format. The rasterization errors (RE_i) were calcu- lated for each land category (LC_i) as the ratio of the difference between the area of LC_i in vector format (V_i) before rasterization and the area of LC_i in the raster dataset after rasterization (R_i) to V_i (Liao and Bai 2010). Results of RE_i for two different raster cell sizes were compared, 10 m × 10 m and 20 m × 20 m, respectively. Furthermore, for three of the four land use maps, reclassification process was performed in order to ensure that the same class matches the same correspondent value in the attribute table. Finally, raster datasets were transformed in ASCII raster file to be imported into MCK software.

The algorithm used for the LUCC analysis was the kappa statistic method, which produces a cell by cell comparison and expresses the agreement between two categorical datasets (Van Vliet, Bregt, and Hagen- Zanker 2011). Kappa coefficient of agreement, used in the comparison of two categorical maps, confounds similarity in quantity with similarity of location (Pontius 2000, 2002). For this reason, Pontius (2000) introduces two statistics to account for the difference in similarity in quantity from the similarity in the loca- tion. Hagen (2002) proposed an alternative statistic for the similarity of the quantity called K_{histo} calculated directly from the histograms of two maps (Hagen 2002). Hence the coefficient of agreement kappa is given by the product of two factors: K_{location} and K_{histo}. The first stays for the assessment of the similar- ity in the position of the cell in two compared maps, whereas the second gives an assessment of the quantity of similarity of the same two maps. Kappa statistic was based on the statistical results of the contingency table (Hagen 2002).

The comparison was made on paired land cover maps (LU 1817 and LU 1875; LU1875 and LU 1960; LU 1960 and LU 2006) and lastly on the whole period from 1817 to 2006.

Results

Georeferencing and accuracy results

All maps were georeferenced with first order poly- nomial transformation. More than 100 points of cor- respondence, for each sheet map, were used. The average RMS of around 20 and 50 m were found, for the maps of 1875 and 1817, respectively. The error associated to the transformation was calculated from the link tables by ArcMap. The total error is computed as the RMS sum of all the residuals of link points. Although the RMS error is a good assessment of the transformation's accuracy, the transformation may still contain significant errors (http//:www.esri. com). To avoid this risk, it is necessary to enter a sufficient number of control points.

Results of MapAnalyst calculations for visual accu- racy assessment for the two maps of 1817 and 1875 are reported in Table 3.

Table 3. Results of MapAnalyst calculations for visual accuracy assessment in terms of standard deviation and root mean square position error for the two maps of 1817 and 1875.

Map year	Standard deviation (m)	Root mean square position error (m)
1817	112.6	14.4
1875	159.3	18.2

LUCC analysis

According to the classification adopted, time series of land use/cover maps of the four periods under study were developed and are displayed in Figure 4. Areas occupied by the land use/cover classes and percen- tage of coverage are reported in Table 4, which includes the evolution of land cover proportion. In the reference year (1817), agricultural and forest areas covered about a half of the total area, that is, 24% and 29%, respectively. If vineyards (13%) were added to the agricultural areas, the percentage area under agricultural production would be 38%. Urban areas were almost discontinuous (8% of the study area) with only 2% organized as small settlements. Sparsely vegetated areas were at their maximum level of cover- age during this period. Errors in rasterization process (RE_i) for the raster cell size of 10 m × 10 m were lower than that for the 20 m × 20 m cell size. This result confirms that the larger the absolute value of the cell size is, the bigger the error is (Liao and Bai 2010). Anyway the RE_i values for the two raster resolution are very close to each other. Results of RE_i for cell size of 10 m × 10 m are reported in Table 5.

Land cover change in the period 1817–1875

During the period from 1817 to 1875, 55% (5503.35 ha) of the total area remained unchanged, while the remaining parts experienced land cover change. The land cover change, which includes an assessment of the net gain or net loss (in the last row), are reported in Table 6. The annual rate of change between 1817 and 1875 was about 77 ha yr^{-1}. The results show that there was an increase in areas covered by continuous urban fabrics, whereas agricul- tural, discontinuous urban fabric, and sparsely vege- tated areas decreased. Total areas with no data however remained unchanged.

Land cover change in the period 1875–1960

The period from 1875 to 1960 registered the highest amount of LUCC of the entire period studied. About 63% (6289.4 ha) of the total area was subjected to a land cover change. However, the annual rate of change of about 74 ha yr^{-1} was less than that for the period between 1817 and 1875. Results of land cover change during this period are reported in Table 7. During this period, an increase in agricul- tural areas and continuous urban fabrics was observed, while the other five land cover classes experienced net losses.

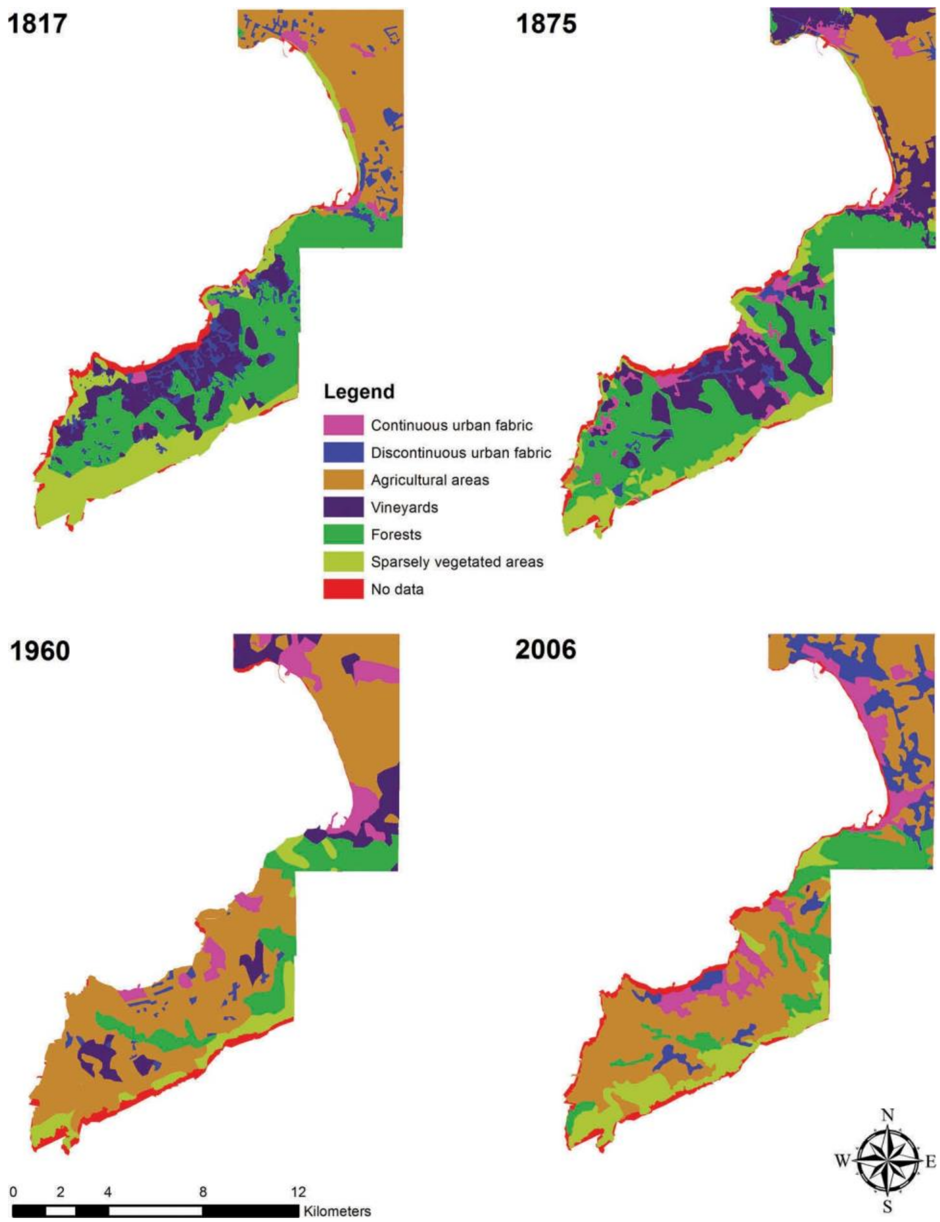

Figure 4. Time series of land cover maps from 1817 to 2006.

Table 4. Area and percentage of land cover classes of the total study area for the different time steps: 1817, 1875, 1960, and 2006.

Land cover classes	Land area (ha) 1817	% of total area	Land area (ha): 1875	% of total area	Land area (ha): 1960	% of total area	Land area (ha): 2006	% of total area
Continuous urban fabric	238	2	725	7	875	9	980	10
Discontinuous urban fabric	842	8	288	3	166	2	1231	12
Agricultural areas	2403	24	1598	16	5689	57	4660	47
Vineyards	1339	13	2453	25	986	10	4	0
Forests	2913	29	3385	34	1196	12	1390	14
Sparsely vegetated areas	1803	18	1088	11	662	7	1126	11
No data	433	4	433	4	396	4	579	6
Total	9970	100	9970	100	9970	100	9970	100

Table 5. Rasterization errors (RE_i) calculated for each land category (LC_i) for raster cell size of 10 × 10 m.

Land cover classes	RE (%): 1817	RE (%): 1875	RE (%): 1960	RE (%): 2006
Agricultural areas	−0.15	1.10	0.00	0.01
Continuous urban fabric	−0.02	−0.07	0.00	0.07
Discontinuous urban fabric	−0.28	−0.21	0.14	0.03
Vineyards	−0.11	−0.65	−0.04	−8.00
Forests	0.45	−0.03	0.02	0.03
Sparsely vegetated areas	0.01	−0.39	−0.14	−0.04
No data	−0.06	−0.01	0.08	−0.02

Land cover change in the period 1960–2006

In the period beginning from 1960 till 2006, 48% (4833.68 ha) of the total area was subject to change. The annual rate of change of 105 ha yr^{-1} was the highest over the period under study. Results are reported in Table 8. During this period, there was a reduction in agricultural areas and vineyards, while continuous urban fabrics and the other four classes experienced net gain.

Land cover change over the entire period of study

Considering the entire period from 1817 to 2006, 61% (6113.63 ha) of the total area was subject to LUCC. About a half of the total area was covered by agricul- tural areas in 2006 compared with only 24% in 1817. Vineyards almost disappeared from 1337 ha in 1817 to 3.7 ha in 2006, while continuous and discontinuous urban areas increased from a total of 10% to 22% of the total land cover (Figure 4).

Results of kappa statistic

The period from 1817 to 1875 had the highest kappa values of 0.44, while the lowest value of 0.24 was regis- tered between 1875 and 1960. Low value of kappa indi- cates a big dynamism in the LUCC change. Figure 5 reports results of a comparison of the kappa index for each land use/cover classes in the three different periods considered in the study. Kappa index is given by the product of two other indices that are reported in Table 9.

Table 6. Contingency table of land cover change for the period 1817–1875.[a]

1817/1875	No data	Agricultural areas	Continuous urban fabric	Discontinuous urban fabric	Vineyards	Forests	Sparsely vegetated areas	Sum 1817
No data	270.9	1.2	22.1	5.9	27.6	7.9	97.3	433
Agricultural areas	5.7	1416.2	72.1	46.5	834.5	7.8	19.2	2403
Continuous urban fabric	6.1	13.6	172.3	7.7	23.4	8.4	5.5	237
Discontinuous urban fabric	0.2	115.6	184.0	73.6	310.4	135.3	22.1	842
Vineyards	2.6	0.0	102.4	54.4	648.0	489.0	41.8	1339
Forests	1.0	6.5	85.5	49.8	529.0	2130.0	109.4	2913
Sparsely vegetated areas	145.6	45.0	83.2	49.7	80.0	606.3	792.4	1803
Sum 1875	433.0	1598.3	721.9	287.7	2452.6	3385.2	1088.4	9970
Assessment of change	No change	Net loss	Net gain	Net loss	Net gain	Net gain	Net loss	

Notes: Results represent the areas under change and are expressed in ha.
[a]The terms total gain, total loss, and no change are referred to the map of 1817 (Hewitt and Escobar 2011).

Table 7. Contingency table of land cover change for the period 1875–1960.[a]

1875/1960	No data	Agricultural areas	Continuous urban fabric	Discontinuous urban fabric	Vineyards	Forests	Sparsely vegetated areas	Sum 1875
No data	91.7	202.9	82.2	8.9	16.6	5.5	25.0	433
Agricultural areas	5.6	1363.2	161.2	0.0	58.0	10.2	0.0	1598
Continuous urban fabric	4.6	349.0	280.1	32.2	37.9	3.1	15.0	722
Discontinuous urban fabric	4.3	177.6	45.6	24.6	24.2	11.2	0.1	288
Vineyards	8.1	1407.1	256.6	64.7	554.5	139.6	21.7	2453
Forests	33.9	1808.0	14.5	35.2	274.2	990.4	227.8	3385
Sparsely vegetated areas	247.7	379.0	34.6	0.5	20.0	35.4	371.0	1088
Sum 1960	396.0	5686.8	874.8	166.1	985.3	1195.4	660.6	
Assessment of change	Net loss	Net gain	Net gain	Net loss	Net gain	Net gain	Net loss	

Notes: Results represent the areas under change and are expressed in ha. [a]The terms total gain, total loss, and no change are referred to the map of 1875 (Hewitt and Escobar 2011).

Table 8. Contingency table of land cover change for the period 1960–2006.[a]

1960/2006	No data	Agricultural areas	Continuous urban fabric	Discontinuous urban fabric	Vineyards	Forests	Sparsely vegetated areas	Sum 1960
No data	188.0	38.5	2.9	7.2	0.0	3.3	156.1	396.0
Agricultural areas	241.8	3361.1	531.6	791.7	3.7	305.0	454.3	5689.2
Continuous urban fabric	86.3	190.0	352.5	213.3	0.0	10.6	22.4	875.0
Discontinuous urban fabric	9.9	94.3	32.1	25.8	0.0	4.2	0.0	166.2
Vineyards	17.3	601.0	61.6	165.5	0.0	134.0	6.2	985.5
Forests	5.5	291.5	0.0	19.6	0.0	800.4	78.9	1195.9
Sparsely vegetated areas	30.0	83.1	0.0	8.1	0.0	132.4	407.5	661.1
Sum 2006	578.7	4659.5	980.7	1231.2	3.7	1389.8	1125.5	
Assessment of change	Net gain	Net loss	Net gain	Net gain	Net gain	Net gain	Net loss	

Notes: Results represent the areas under change and are expressed in ha.
[a]The terms total gain, total loss, and no change are referred to the map of 1960 (Hewitt and Escobar 2011).

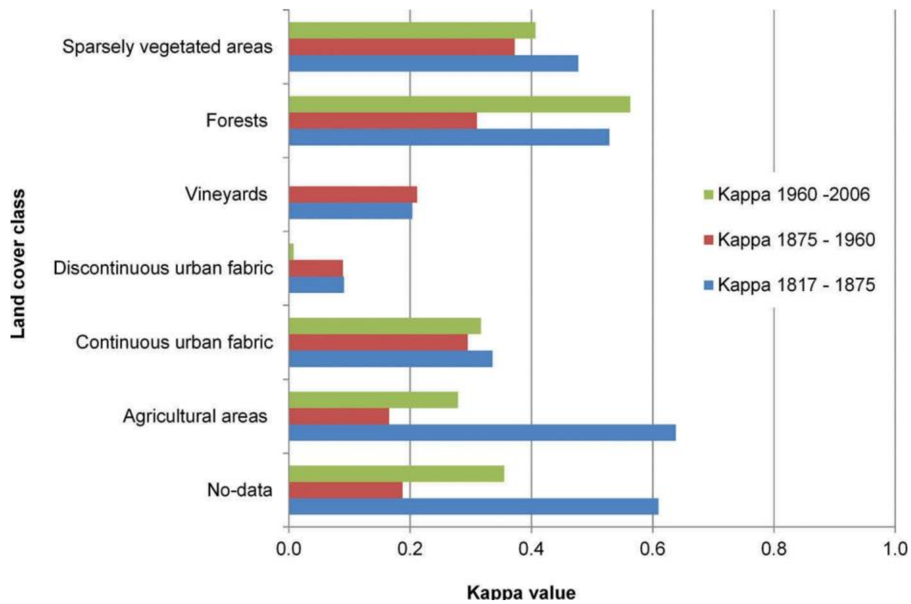

Figure 5. Kappa statistic value for the seven classes. Comparison has to be read only class by class over the three periods of time (Hewitt and Escobar 2011).

Discussions

A big transformation of land use/cover of the study area was observed in the last 200 years, whereas only 39% of the total land area remained unchanged during the period of analysis. The transformation is mainly due to the change of land cover from vineyards to olive and citrus groves.

Land cover development

Agricultural areas

The current economy of Campania region is primarily based on agriculture (Albanese et al. 2007; Pindozzi et al. 2013); about 50% of the land of whole region is covered by agriculture. Di Gennaro, Innamorato, and Capone (2005) demonstrated the amount of land use/cover transformation in the last 50 years in the Campania region, especially due to the intensification and specialization in agriculture. Nevertheless rural areas of the region seem to be oriented toward a dis- organized land use with the impact being land degra- dation (Di Gennaro, Innamorato, and Capone 2005). The present study confirms that agriculture registered the highest growth in the period immediately before the 1960, followed by a tremendous urban develop- ment, especially in the Sarno river valley in the north- ern part of the study area (Figure 6).

Vineyards

During the nineteenth century, vineyards were largely cultivated due to the high level of wine consumption by the local population. The per capita wine consumption was approximatively 150 L yr^{-1} and it was believed to

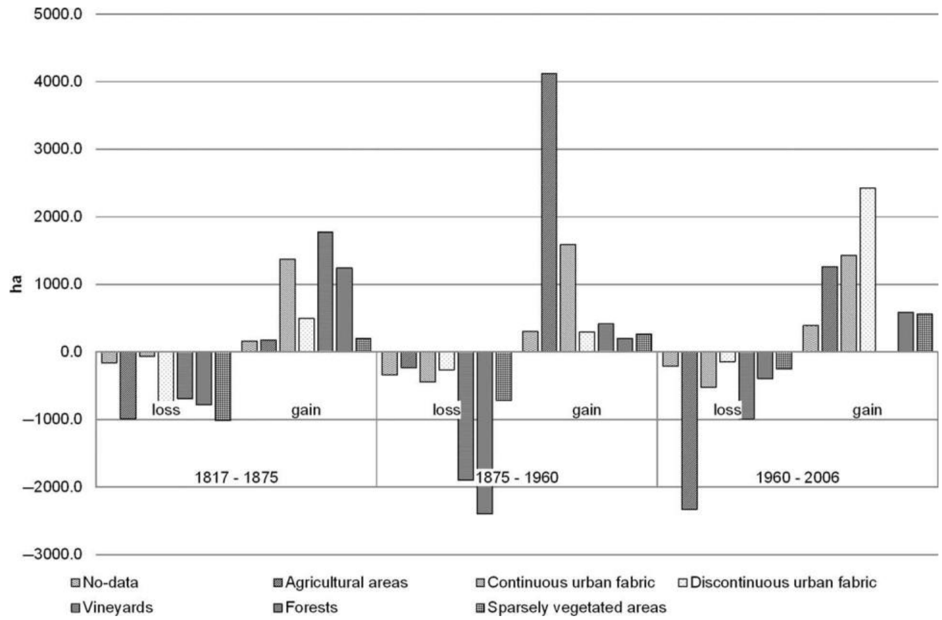

Figure 6. Absolute changes in land use/cover, expressed in ha, in each period studied.

be due to the poor nutrition and widely spread poverty during the period. This can be observed from the increase in percentage of land covered by vineyards from 13% in 1817 to 25% in 1875 as shown in Table 4. There was a decline in wine consumption during the last three decades of the nineteenth century (Tino 1993). According to tax surveys in that period, the Neapolitan population increased by about 100,000 units, whereas the consumption of wine fell from an annual average of 465,785 hectoliters in 1872 to 407,885 hectoliters in 1876. Between 1897 and 1901, there was a further decline in consumption from about 86,000 bottles to 76,000 bottles. Unofficial sources reported a probable increase in the cost of the wine, which made it less affordable. The per capita wine consumption of inhabitants of the study area was observed to gradually decline during the study period, and this perhaps explains the reduction in land occu- pied by vineyards (Table 4, Figure 6).

Urban areas

Study area experienced rapid urbanization in the per- iod from 1960 to 2006. The 1960s is generally reported as an important period of industrializations and urba- nizations in Italy (Di Gennaro, Innamorato, and Capone 2005). If urban class is considered as the sum of both continuous and discontinuous areas, then more than 1300 ha of agricultural areas were transformed into urban areas in the period analyzed (Table 8). Another important aspect is that TCI/CNR map devel- oped perhaps underestimates the discontinuous urban areas. This is because the original maps did not have a specific symbol for this class in the legend. Consequently, the identification of this class leads to positioning errors as confirmed by the corresponding low kappa values for discontinuous urban areas class (Figure 5). The low kappa values observed in the per- iod from 1960 to 2006 is perhaps explained by low values of the K_{location} (0.12) that expresses similarity of spatial allocation. On the other hand, K_{histo}, which is a measure of the quantity in similarity of two maps, shows greater value of 0.73.

Forests and sparsely vegetated areas

As for agricultural and urban areas, forested areas were also subject to a huge land cover change in the last 50 years. Forests in the whole Campania region suffered the effect of increasing urban sprawl and intensification and specialization of agriculture, especially in the coastal plains and hills (Migliozzi et al. 2010; Di Gennaro, Innamorato, and Capone 2005). The study areas have seen a drastic reduction in forests cover during the period from 1875 to 1960, most of which were substi- tuted by agricultural areas (Figure 4). In the subsequent period from 1960 to 2006, forest cover was still persistent on the upper part of the peninsula with a very small expansion in areal coverage mainly due to natural recolonization.

No data areas

Old maps reported numerous sandy beaches along the coastline of Sarno river basins. Progressive urbanizations of the coast eroded the cultivated land areas and the residual plain forests (Migliozzi et al. 2010). The use of *no data* class allowed for the estimation of the evolution of the coastline of the study area. Land cover that was lost during the years from 1817 to 2006 was recorded as gain in the *no data* class. On the contrary, loss of the *no data* class is an estimation of the development of other land cover classes at the coast (Tables 6–8). An example in this case is transformation of urban areas to harbors.

Kappa statistic

From results in Table 9, it can be observed there was more similarity in the quantity but not in the location of some of the pairs of maps compared. Even if we would not expect a similarity, it is not possible to exclude that, in lower part, the dissimilarity can be attributed to the imperfect overlap of the two maps (Wallace and van Den Heuvel 2005) encompassed in the RMS value of georeferencing process (see Georeferencing and Accuracy Results section). Errors in the historical maps are related to the operational modalities of the field survey. Usually, the errors became more evident progressively from the urban centers to hilly areas. Such concern is well explained by Wallace and van Den Heuvel (2005).

Accuracy of maps

In the present study, the high level of accuracy of the maps used minimized some of the problems reported in other studies such as inadequacies due to delinea- tion technique selected, or absence of a consistent triangulation network (Skaloš et al. 2011). Mutual inner inconsistencies of the pre-geodetic maps (Bitelli, Cremonini, and Gatta 2014) were also mini- mized. First step was to check for the accuracy of the maps (Galluccio 2007), then the information gener- ated was validated with the help of supplementary data. The accuracy of the 1817 maps was confirmed by the good overlapping of the georeferenced maps with current CTR maps of Campania region. These maps were georeferenced with an average RMS error of a few tens of meters. Moreover, it was possible to

Table 9. Results of $K_{Location}$ and K_{Histo}.

	$K_{Location}$	K_{Histo}
1817–1875	0.60	0.74
1875–1960	0.49	0.49
1960–2006	0.43	0.71

recognize the origin of the current symbolism adopted by IGM on these maps. The vineyards class symbolism adopted in 1817 is very similar to the corresponding class on the map of 1875 (Table 2).

Conclusions

This study aimed at documenting the LUCCs in Sorrento peninsula and parts of the Sarno river basin of southern Italy over the past 200 years. Furthermore, the LUCC analysis gave important results for the study area. The landscape is currently protected and all the landscape management plans are oriented to the preservation of the current state. This study demonstrated that until the 1960, 25% of the peninsula was covered by vineyards. As suggested by Verburg et al. (2009), the important driving force of the land cover is explained by the change in the provision of goods and service. In the case study, the driving force was recognized as the reduction in wine consumption of the population (Tino 1993). Lastly, the statistical approach of the MCK software enabled considerations about LUCC analysis.

One of the main achievements of this study was the rebuilding of land use history, with the use of historical GIS, that allows to study “patterns of change over space and time” (Knowles 2002). The limitation of this study is that it was only possible to analyze conversion from one land cover category to another analysis in the sense reported by Jansen and Gregorio (2002), because broad classes were used in the classification of land cover. Otherwise studies based on cadastral maps gave the advantage of providing information concerning eco- nomic, social, and cultural factors, which can be used to develop explanations of changes in landscape pat- terns (Bender et al. 2005) but gave more errors in placement of landscape boundaries that are essential when comparison is made using GIS software.

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ORCID

Stefania Pindozzi http://orcid.org/0000-0001-9301-7984 *Elena Cervelli* http://orcid.org/0000-0003-3218-3641 *Alessandra Capolupo* http://orcid.org/0000-0002-4103-1992 *Collins Okello* http://orcid.org/0000-0001-9165-0989
Lorenzo Boccia http://orcid.org/0000-0001-7993-9480

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