

Land use and landscape pattern changes driven by land reclamation in a coastal area: the case of Volturno delta plain, Campania Region, southern Italy

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Abstract The paper provides documentary evidence of the direct impacts on the coastal setting in the northern Campania (southern Italy) region, crossed by the Volturno River, that have led to dramatic alterations of alluvial channels, floodplain and the deltaic environment, aside from the coastline retreat following four centuries of land reclamation. The Volturno delta plain is characterized by an outer delta formed mainly by beach ridges, and an inner plain containing several depressions of drained marsh regions. Until the beginning of the last century, this area was the site of swamps and ponds bearing a high incidence of malaria. Historical analysis coupled with a cartographic restitution in a geographic information system environment has produced documentary evidence of the geomorphological evolution of the coastal sector and has allowed the reconstruction of relevant landscape and hydrographic changes since the end of the seventeenth century, when—during the Spanish vice-kingdom—it was subjected to major land reclamation. The availability of reclaimed lands along the coastal alluvial plain promoted the development of agriculture and farming, as well as a strong coastal urbanization. As a consequence, a landscape fragmentation increased significantly between the 1960s and the 1990s; built-up land area increased as well, overgrowing to the sea. An overall reduction in high-quality ecosystems (humid coastal setting, lacustrine/marshy back-dune area and

beach-dune system) is recorded, resulting in biodiversity loss and a dramatic reduction in environmental quality. The outcomes of this research will be beneficial to society for better decision-making over these coastal area applications, in a sustainable manner, especially in these countries that are still experiencing land reclamation.

Keywords Volturno River · Campania · Coastal area · Reclamation intervention · Land use changes · GIS

Introduction

Alluvial coastal systems are heavily subjected to natural constraints as they are the key point of land–sea interaction. Along these depositional settings, in particular, the soft coastal landscapes of beaches and sand dunes, the deltaic systems and the coastal wetlands represent fast-responding and mobile geomorphic systems that are highly sensitive to any kind of environmental change, especially those deriving by human activities that affect the landscape pattern structure and, in turn, the ecological processes in the related ecosystems (Hinrichsen 1998; Walsh 2013; Anthony et al. 2014). Most of the world's coastal wetlands are located in deltas and host natural ecosystems of great ecological and economical value (cf. Mallinis et al. 2011). The coastal wetlands are very sensitive to human impacts leading to land use/land cover changes and habitat degradation (Leuven and Poudevigne 2002; Ward et al. 2002; Papastergiadou et al. 2008; Li et al. 2014). The Habitats (92/42/EEC) and Birds Directives (79/409/EEC) have addressed policies to protect and preserve such ecosystems in the frame of Natura 2000 network. The deltaic ecosystems, in particular, received special attention in the Ramsar

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convention and EU Water Framework Directive (WFD 2000/60/EC 2000).

Until the beginning of the last century, most of the coastal areas escaped direct human impacts as they were sites of swamps and ponds bearing a high incidence of malaria (Anthony et al. 2014; Pranzini et al. 2015). In the last decades, however, the land reclamation, in primis, and the development of tourism industries, coupled with sea level rise and coastal erosion, have exposed these areas to multiple and often combined agents of disturbance, and in some case, human pressure has led to the expansion of coastal cities to the sea. In particular, land reclamation in coastal areas represents one of the most important drivers to the degradation and loss of coastal systems (Lotze et al. 2006; Airoidi and Beck 2007). On the one hand, it brings economic benefits by recovering land for grazing and agriculture; on the other hand, it results in disturbance to the coastal ecosystems, increasing also pollution and eutrophication of soil and waters (Perry et al. 2008; Verde et al. 2013; Di Giuseppe et al. 2014; Sofia et al. 2014; Jin et al. 2016; Zhu et al. 2016a; among others). Changes have significantly affected also the landscape on varying time and spatial scales and, above all, the hydrographic system that supply sediments to the delta plains and the strand plains, with consequent accelerated coastal erosion and further depletion of the coastal environment, habitat degradation and reduction in biodiversity (Healy and Hickey 2002; Verde et al. 2013; Hernández et al. 2016; Zhu et al. 2016b).

Landscape thus reflects the long-term interactions between people and the environment they inhabit (cf. Varga et al. 2013, among others), especially in a fast-growing country. Carter and Woodroffe (1994) stated that “to ignore the role of humans and their impact on coastal evolution would be fallacious.” The long-term dynamics of coastal geomorphological systems are often overlooked by managers and decision-makers, who usually circumscribe their management action within short time spans (1–5 years) and tend to view the river system and the related coastal settings as a stable set, considering their current condition as natural and permanent (Carter and Woodroffe 1994). Scientific advances are thus necessary to support a sustainable utilization strategy by highlighting the precise linkages between catchment-coastal processes and systems and the impacts on, and feedback effects from socio-economic systems and activity levels. In this perspective, it is necessary to identify and analyse the regional changes which are primarily the result of drivers and pressures in the coastal zone. As the landscape represents the mosaic and palimpsest inherited from past environments, the historical reconstruction of both land use–land cover and morphological changes, as well as the analysis of landscape dynamics, is of paramount importance for the

rational development and utilization of a coastal setting (Salomons and Turner 2005; Smiraglia et al. 2007; Almeida et al. 2016).

The present study focused on the morphologic, hydraulic and land use changes that have occurred during the last 150 years in the northern Campania Plain, a large reclaimed alluvial plain along the eastern Tyrrhenian Sea in southern Italy. The site is representative of the main land use and hydro-geomorphological changes that the whole Campania Plain faced during the last half century.

The aim of this work was to reconstruct the main geographic man-induced evolution by using geomorphological methods and to examine the historical land use and land cover changes in a landscape context from 1957 to 2012, using GIS. The results herein presented are part of a larger study aimed at the environmental characterization of a coastal setting in the frame of an Integrated Coastal Zone Management (ICZM; Ruberti et al. 2008; Verde et al. 2013).

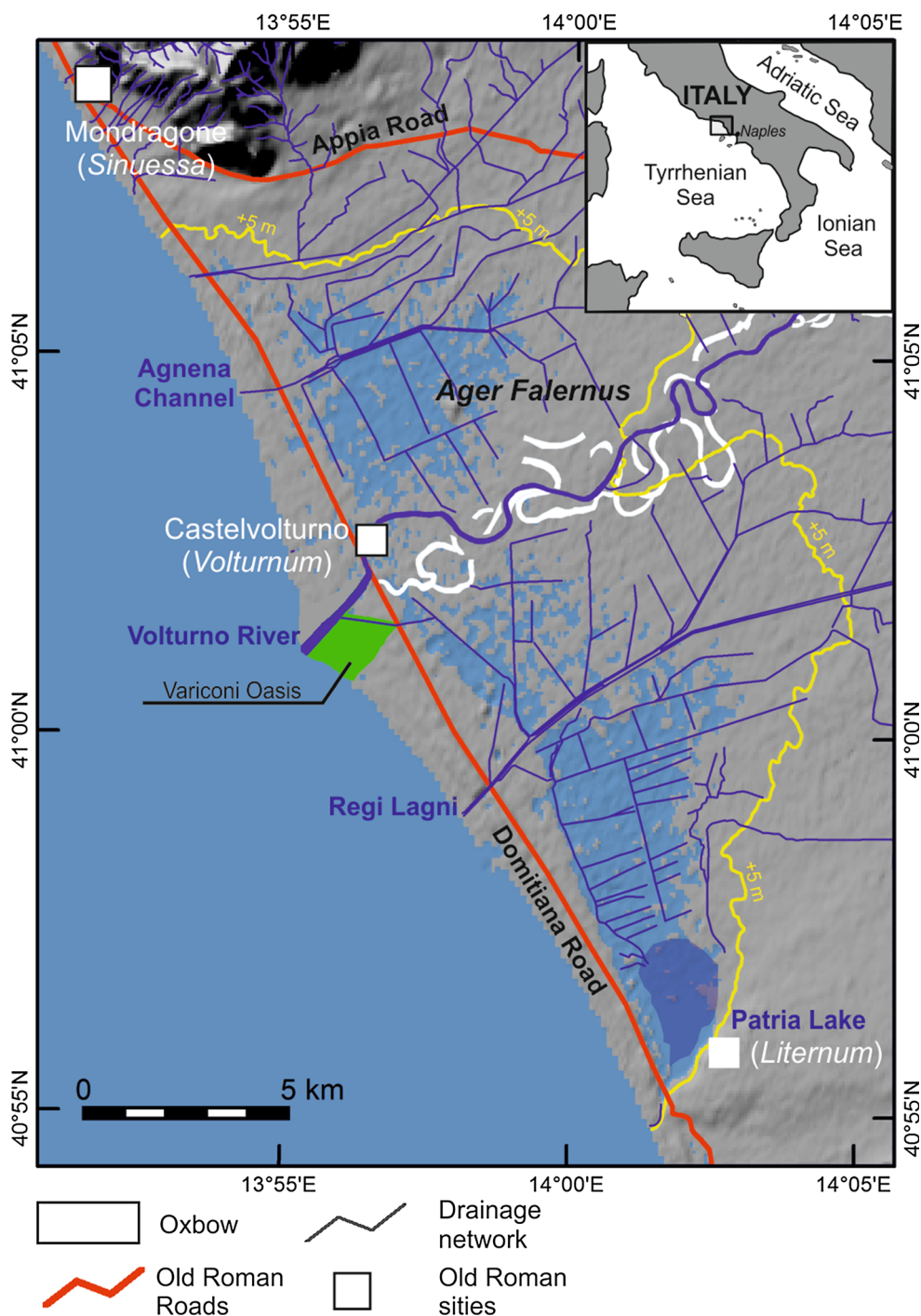
In this perspective, different historical maps and aerial photographs of the coastal floodplain have been collected, digitized and analysed in GIS environment; this enabled us to obtain: (1) a qualitative reconstruction of the landscape changes in the last 150 years and (2) a reconstruction of the land reclamation work and resulting major changes in land use and landscape pattern over the last 100 years (along with the coastal wetland loss and the growth of the urban land over the same time span).

Study area

The alluvial deltaic coastal plain of the Volturno River, the largest river in southern Italy, was considered for the present study from longitude 13°52' to 14°04'E and latitude 40°54' to 41°07'N. The 5 m above sea level contour line was used as perimeter (Fig. 1), as it is considered the outer limit of the palaeo-gulf before the prograding of the Volturno River delta since 6500 ky BP (cf. Amorosi et al. 2012). The total area analysed encompasses about 188.4 km².

With a total area of about 1350 km², the Campania Plain is one of the largest plains in southern Italy. As most of the coastal plains around the Mediterranean area, this one has developed following the Holocene glacio-eustatic sea level rise, after the Last Glacial Maximum that led to a worldwide flooding of shelf settings. The following highstand phase, in the last about 6000 ky BP, resulted in the aggradation and progradation and the development of the alluvial plain, leading to the formation of a wave-dominated delta system, with flanking strand plains forming beach-dune ridges partially enclosing lagoon–marshy areas (Fig. 1). Beach and lagoon environments persisted up to

Fig. 1 Digital Elevation Model of the study area (Shuttle Radar Topography Mission dataset). Inland blue zones correspond to continental water bodies and/or areas with elevation ≤ 0 m above sea level. The location of the archaeological remains of Roman Age (*Sinuessa*, *Volturnum* and *Liternum*) is reported, as well as the tracks of the Roman Appia and Domitiana roads (modified from Sacchi et al. 2014). In green, the protected coastal sites (SPA and SCI); in yellow, the 5 m contour line which outline the study area



2 ky BP; crevasse splay and overbank fluvial processes filled most of the swamp areas. The remnant of the area previously occupied by the larger wetland that formed along the coast during the last thousand years nowadays lies at an elevation between 0 and -2 m with respect to the present sea level and is partly preserved in several swamps and a small lagoon (Lake Patria; Fig. 1).

Landscape evolution in historical time

Based on stratigraphic data, the location of the inner continental shelf and the associated coastline has been relatively stable since the Roman time (Amorosi et al. 2012; Sacchi et al. 2014). Historical evidences for the occurrence of such a beach-dune system and coastal lagoons are reported by Strabone (2007); this is also confirmed by the tracks of two major Roman roads: one (Domitiana Road)

running along the sandy coastal belt and the other (Appia Road) crossing the coastal plain along its inland margin, thus avoiding the wetland area (Fig. 1).

Since that time, in fact, the *Clanius* (Clanio river; Fig. 2) had been a natural barrier between Neapolis and its coastal setting and the *Ager Campanus*, as it generated ponding and swamps. Livio, Valerius Maximus and Virgilio describe *Liternum*, located at the mouth of *Clanius*, as besieged by water and so degraded as to be considered *ignobilis vicus* (ignoble village). The negative effects of this “barrier” took highest negative contours in the Middle Ages since this torrential groove generated deadly swamps and the territory was heavily affected by the scourge of malaria, limiting the connection between coastal and interior lands (Fiengo 1988).

Marshlands covered most of the coastal plain until the beginning of the nineteenth century. The historical maps of Magini (1620) and De L’Isle (1711) constitute some of the oldest, small-scale, cartographic documents that have provided important information on the general setting and features of the Campania coastal zone before the reclamation, although not georeferenced (Fig. 2a). No significant landscape and hydrographic changes occurred until the end of the sixteenth century, when during the Spanish vice-kingdom by Count of Lemos, Don Pedro from Toledo,

ambitious reclamation works were carried out (Fiengo 1988). The first reclamation works interested the Clanio River that was canalized, becoming the Regi Lagni Canal (from the Latin term *lagnum* for dykes of water and collecting canals of stagnant or rain water) (Fig. 2b). The latter represent a remarkable work of hydraulic engineering aimed at draining the marshes along the entire course of the river that was rectified in order to accelerate the water flow, and the Clanio River inlet of the *Literna Palus* (Lago di Patria–Patria Lake) was diverted directly into the Tyrrhenian Sea across the dune system.

Most of these marshy areas were reclaimed for agriculture and other human activities from the beginning of 1800s until the early 1900s. Part of the river’s water was diverted and canalized, with the aim of elevating the land surface by filling the marshy areas with alluvial sediments, eventually completely modifying the drainage network. Such canals branched into other diversion canals reaching the inner parts of the sedimentation tanks (Viparelli 1965).

Coupled with increased anthropogenic impact in the last century, this resulted in severe morphological and environmental deterioration (Ruberti et al. 2008; Verde et al. 2013; Balassone et al. 2016).

The natural relevance of the territory, although seriously threatened and undermined in part, has been recognized

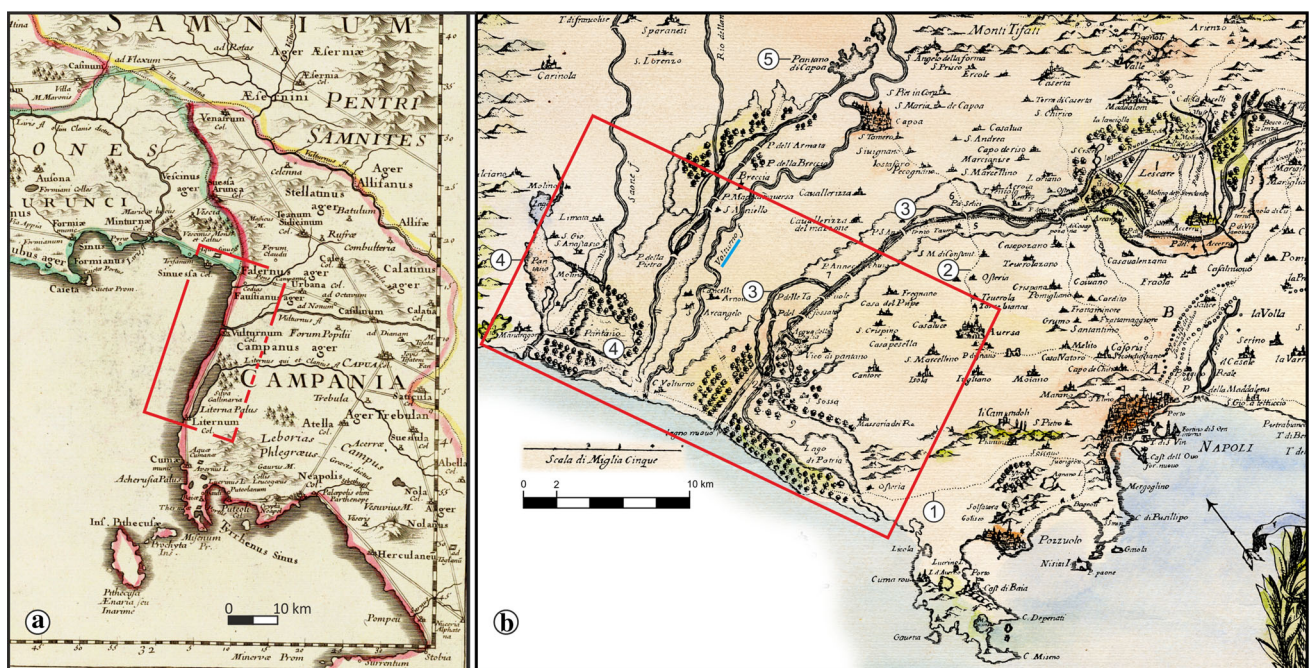


Fig. 2 a Historical topographic map of lower Volturno River plain area (De L’Isle 1711) highlighting the natural river network before the incoming reclamation. b “Campania Felice” Map (De Silva 1692). The cartographic restoration follows and upgrades a previous one, made for Count of Lemos in 1615. Dotted lines represent road tracks (along with the Domitiana (1) and Appia (2) roads). The map shows the most important reclamation interventions made on the river

courses north and south of the Volturno River. South of the river, the marshy area across the whole ancient Clanis River (3) is evidenced by the ragged lines north and south of the canal (“lagno”) replacing the natural course. North of the Volturno River, the channels were diverted to dry widespread marshy areas (“Pantano” (4), close to Mondragone, and “Pantano di Capoa” (5), close to Capua village). Red boxes refer to the study area

with the establishment of special protection areas (SPAs) and sites of community importance (SCI) by the Office of Territorial and Environmental Policies of the Campania Region in 2005.

Materials and methods

To trace the processes and geomorphological changes that have occurred in the study area, an extensive cartographic documentation (topographic maps, ortho images, aerial photographs) has been acquired covering a period of about 400 years, starting from 1620: the oldest maps allowed a qualitative assessment of the landscape evolution occurred up to the end of the 1880s; the more recent maps have been acquired as raster files in tiff format to 300 and 1200 dpi and georeferenced through the GCPs (Ground Control Points) technique, using as base map the georeferenced Topographic Regional Map (CTR) of the Campania Region (1:25,000 scale) and GeoMedia® Pro 6.1 with “Image Registration” tool which allowed to resample the maps by bilinear interpolation method. All new data were re-projected to UTM Zone 33 (WGS84).

It is known that the accuracy of the above maps could be affected by errors induced either by digitization and georeferentiation, the latter being more common if the original map was realized in different coordinate systems. In this study, the root mean square error (RMS error) calculated for all the maps used to draw the land use/land cover (LULC) polygons is lower than the pixel resolution

(Table 1). Only the 1887 topographic map shows higher RMS errors; for this reason, the reconstructed hydrographic network (vector data) has been corrected based on the vector data related to the 1957 map.

Data concerning the geomorphological setting, hydrographic pattern and LULC have been acquired through the analysis of the above cartographic documentation in a GIS environment with GeoMedia®. Multi-temporal data have been topologically overlapped to facilitate spatial analysis (change, persistence, trend). The general workflow of this study is presented in Fig. 3.

Drainage network identification and classification

Three batches of image data were used to outline the drainage system evolution through time (topographic maps from 1887, 1957, 1987; Table 1). In order to generate the digital materials (vector data), several stages were required: the topographic maps were scanned and then imported into GIS environment; the maps were analysed by manual on-screen interpretation and the main linear elements (i.e. rivers and canals) were digitized.

The hydrographic network obtained was used to: (1) obtain the total number of branches (N); (2) calculate the total stream length (L ; expressed in km); (3) calculate the area covered by the hydrographic network (A); (4) quantify the drainage density ($D = L/A$; km/km², estimated as the ratio of total length of channels of all order in the basin to the drainage area of the basin (Horton 1932); (5) quantify stream frequency ($F_s = N/A$) of the area for each year in

Table 1 Data used (IGMI Italian Military Geographical Institute; CTR Carta Tecnica della Regione Campania) and analysis: LULC land use and land cover; HN hydrographic network; RMS (root mean square) error

Data	Year	Resolution (m)	RMS error (m)	Purpose
Toposheets IGMI. Carta d’Italia (1:50,000 scale):	1887	3.1 × 3.1		HN
171 II <i>Mondragone</i>			15.09	
172 III <i>Casal di Principe</i>			29.56	
184 IV <i>Marano di Napoli</i>			24.04	
Aerial photographs	1957	1.5 × 1.5	0.87	LULC
Toposheets IGMI. Carta d’Italia (1:25,000 scale):	1957	4.2 × 4.2		LULC, HN
171 II NE <i>Mondragone</i>			2.44	
171 II SE <i>Castel Volturno</i>			1.67	
172 III NO <i>S. Andrea</i>			2.53	
172 III SO <i>Vico di Pantano</i>			1.31	
184 IV NO <i>Lago di Patria</i>			2.30	
Toposheets CTR. (1:25,000 scale):	1987	1.6 × 1.6		HN
Tav. 14 <i>Mondragone</i>			0.88	
Tav. 15 <i>Grazzanise</i>			0.99	
Tav. 22 <i>Lago Patria</i>			0.52	
Ortho images	1990	10 × 10		LULC
Ortho images	2012	0.5 × 0.5		LULC

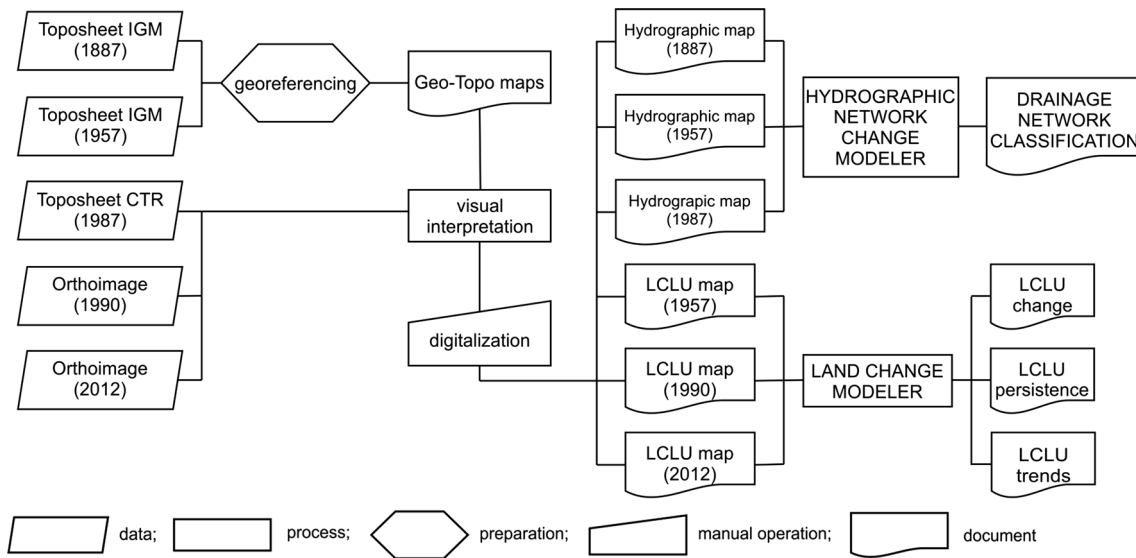


Fig. 3 Data and processes workflow

question (known as the ratio of streams numbers per unit area of the basin; F_s is an index of the various stages of landscape evolution; Horton 1945).

Land use maps

Three batches of images were used to assess land cover changes over the whole area. The land cover categories for 1957, 1990, 2012, were identified by visual on-screen photointerpretation. All the activities were performed in GeoMedia®; the polygons were digitized in a vectorial format and classified with the aim also of field surveys. Moreover, the land use map CORINE Land Cover (CLC)

was used to check and verify the results and to obtain the land use maps. Related land use classes were combined or renamed according to the CLC nomenclature, to give 9 types that were easily recognizable in the images analysed (Table 2). The poor quality of the earliest aerial photographs did not permit a detailed recognition of land cover types.

Changes matrices

Transition matrices have often been used to identify the land use change direction and quantify the changes (cf. Fan and Ding 2016; references therein). The land use maps for

Table 2 Land cover/use type’s classification system used (based on CLC classification)

Code	Land cover/use types	Description
AS	Artificial surfaces	Continuous and discontinuous urban fabric, industrial or commercial areas, road and rail networks and associated land, farm industries, port areas, airports, dump sites
AL	Arable land	Non-irrigated or permanently irrigated lands
VY	Vineyards	Vineyard areas if the vineyard parcels exceed 50% of the area and/or they determine the land use of the area
FT	Fruit trees	Parcels planted with fruit trees: single or mixed fruit species, fruit trees associated with permanently grassed surfaces
GH	Greenhouses	Farming industries with dominant areas of greenhouses
CF	Coniferous forest	Vegetation formation composed principally of trees, including shrub and bush under storey. Coniferous species predominate: <i>Quercus ilex</i> , L., 1753; <i>Pinus halepensis</i> , M., 1768; <i>Pinus pinea</i> , L., 1753; <i>Pinus pinaster</i> , A., 1789; shrub species predominate: <i>Phillyrea angustifolia</i> , L., 1753; <i>Myrtus communis</i> , L., 1753; <i>Pistacea lentiscus</i> , L., 1753; <i>Rhamnus alaternus</i> , L., 1753; <i>Arbutus unedo</i> , L., 1753, <i>Cistus incanus</i> , L., 1753; <i>C. monspeliensis</i> , L., 1753
SV	Sclerophyllous vegetation	Bushy sclerophyllous vegetation, including maquis and garrigue
BD	Beaches, dunes	Areas of bank sand plains prevailingly without vegetation and areas of dunes almost without vegetation or sporadic occurrence of mainly thin
WB	Water bodies	Wetlands, river

each year were overlaid in GeoMedia® to obtain the land use transformation using the overlay analysis with the “Spatial Intersection” tool in Geomedia® environment for the years 1957 to 1987 and 1987 to 2012. Change matrices have been produced as an output and where tabulated. The change matrix shows how each land use/land cover (LULC) pattern changes to other LULC patterns.

Landscape metrics

Landscape metrics are one of the imperative methods for understanding the structure, function and dynamics of landscapes. In order to document land use pattern changes, 3 landscape metrics (NP, PD and MPS) were calculated and analysed for this study (Almeida et al. 2016); the landscape indices are listed in Table 3. They were applied at a class level and were chosen among the ones that influence both landscape pattern and ecosystem functions. For this reason, only area/density metrics were considered to assess fragmentation in the area. Computations were made into a GIS environment. The three coverages of area (1957, 1990 and 2012) were analysed with spatial pattern metrics to quantify the pattern and measure the change in distribution over time of the LULC types defined in Table 2.

To assess the ecological impact of landscape changes, a suite of landscape descriptors have been defined through time that describe habitat characteristics important for various plant and animal species to develop (McKenzie et al. 1992). Among the indices that summarize changes in landscape structure through time, those referring to “patch adjacency” commonly describe landscape changes in an “ecologically meaningful manner” (Smiraglia et al. 2007). The term “boundary” or “contact” usually refers to as neighbouring land use types having shared perimeter. Boundaries between land cover types (natural vs. natural, natural vs. anthropic) define various degrees of contrast in

terms of ecological values. Contacts between landscape elements of very different ecological quality usually result in altered habitat connectivity and capacity (Martin et al. 2008).

Although outside the scope of the present study, an analysis of contacts among the land use polygons was carried out to achieve a qualitative picture of the ecological meaning of the recognized landscape changes, not taking into account the complexity of landscape boundaries nor the landscape shapes.

Results

Reclamation interventions and drainage network modifications

The main landscape and hydrographic network modifications resulting from the reclamation interventions can be easily recognizable in the historical maps of Fig. 4 from the straight canals crossing the lower alluvial plain.

The magnitude of changes is virtually evident when comparing the pattern of drainage systems at different times in maps (Fig. 5) and is highlighted by the quantitative analysis (Table 4). The spatial analysis carried out in GIS environment reveals that in the coastal sectors alone more than 500 km of canals were realized.

Until the end of 1800s, the artificial drainage network summed up to about 126 km of canals (Fig. 5a). In the 1950s, a dense canal network covered the area, with a total length of 525 km that reduced to about 490 km at the end of the 1980s (Fig. 5b, c). The average drainage density was about 1.26 km/km² in 1887, 5.05 km/km² in 1957 and 4.74 km/km² in 1987. In the following years, the extent of the drainage structure remained fairly constant (Fig. 5d).

Table 3 Landscape metrics and related description

Landscape metrics	Description
Area (a_{ij})	a_{ij} is the j th patch area (in hectare) inland-use class i
Area (A)	A is total landscape area (in hectare)
Number of patches (NP)	$NP = n_i$ n_i is the number of patches in land use class i . It measure of the extent of subdivision or fragmentation of the patch type; measures the extent of fragmentation of the entire landscape
Patch density (PD)	$PD_i = \frac{n_i}{A} \times 100$ (A = area of landscape in hectare); n_i = number of patches) <i>The number of patches per 100 hectares.</i> Its basic utility is same as that of number of patches, but it expresses the number of patches on a per unit area basis and thus facilitates comparisons among landscapes of varying sizes
Mean patch size (MPS)	$MPS = \frac{1}{n_i} \sum_{j=1}^{n_i} a_{ij}$ The average area of all patches in a landscape

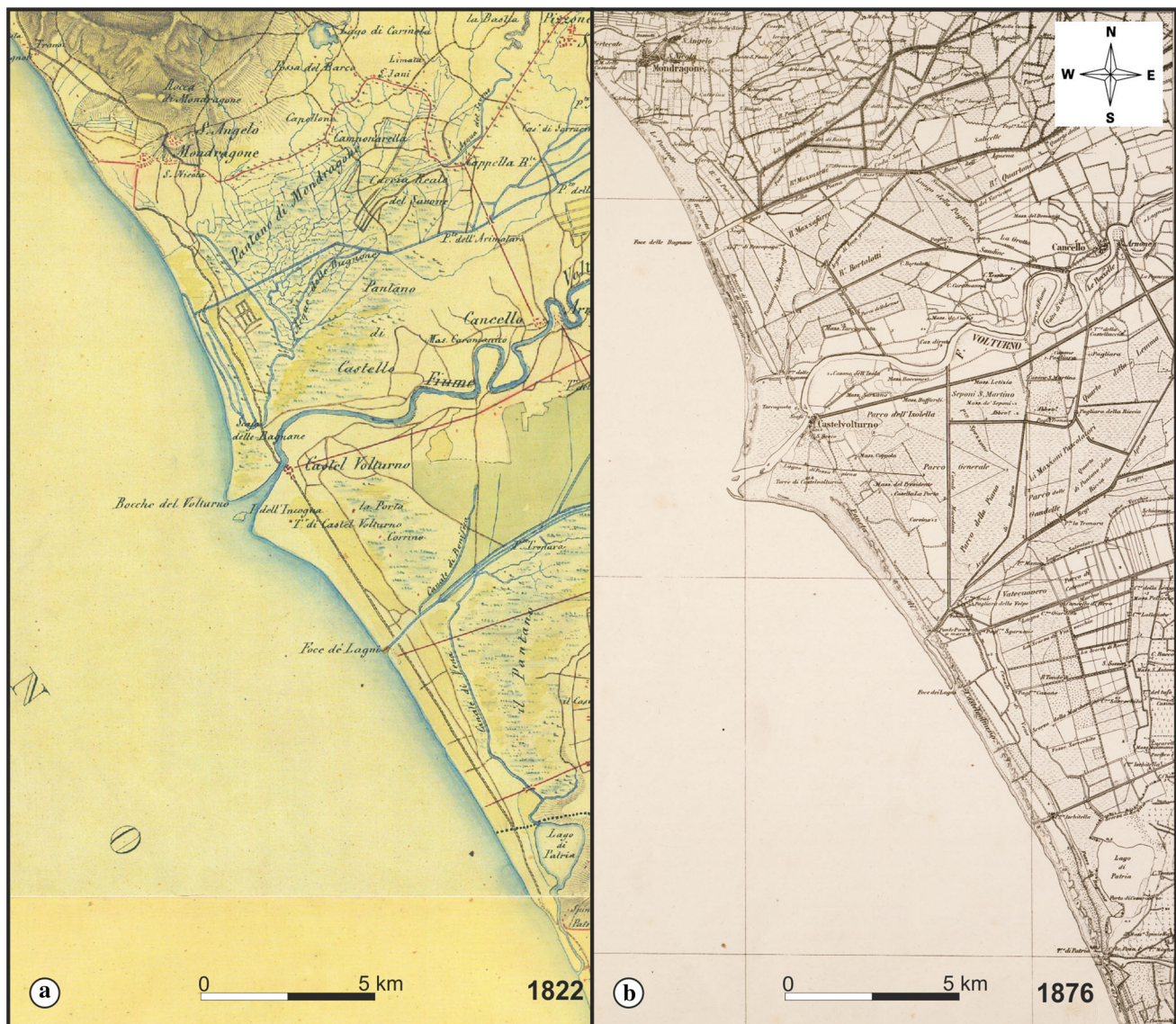


Fig. 4 Historical topographic maps of the lower Volturno River plain: **a** “Carta Austriaca del Regno di Napoli,” Sects. 6 and 7, Column III (1821–1825, in Zerbi 2003); **b** “Carta dell’Italia meridionale” (IGM 1876). Both the maps still show a channel network flowing into a marshy area named *Pantano* (Marsh) di *Mondragone* e *P. Castello*, between the villages of Mondragone and Castelvoturno, north of the Volturno River. South of the Volturno,

the result of the Clanio river reclamation corresponds to the size reduction in the *Literna Palus* (Lago di Patria), the ancient extension of which is recognizable in the *Pantano* (= Marsh) locality (**b**). It is noteworthy that the channels in the northern part were naturally diverted along the shoreline, behind a likely well-developed dune system

Recent landscape and land use changes

Area statistics

Three land use and land cover (LULC) maps were prepared to show the extent and spatial distribution of nine land cover classes in 1957, 1990, 2012. A quantitative assessment of the changes observed is presented in Fig. 6 and Table 5.

In 1957, arable lands (81%), sclerophyllous vegetation (3,7%) and vineyards (4, %) were the predominant land

Fig. 5 Evolution of the pattern of drainage systems following the reclamation works, between the 1880s and the 2010s in the delta plain of the Volturno River. Note the initial progradation of the coastline following the dismantling of the delta apex, turning in a backward trend since the 1960s after the resetting of the delta and the rectification of the coast. It is noteworthy the increase in the built-up land area, overgrowing to the sea (see text for details). **a** “Carta d’Italia,” Foglio 171 II *Mondragone* (IGM 1887); **b** “Carta Topografica d’Italia” (IGM 1957); **c** “Carta Topografica Programmatica Regionale della Campania” (Regione Campania 1987); **d** Digital copy of aerial photograph (Compagnia Generale Riprese Aeree 2012)

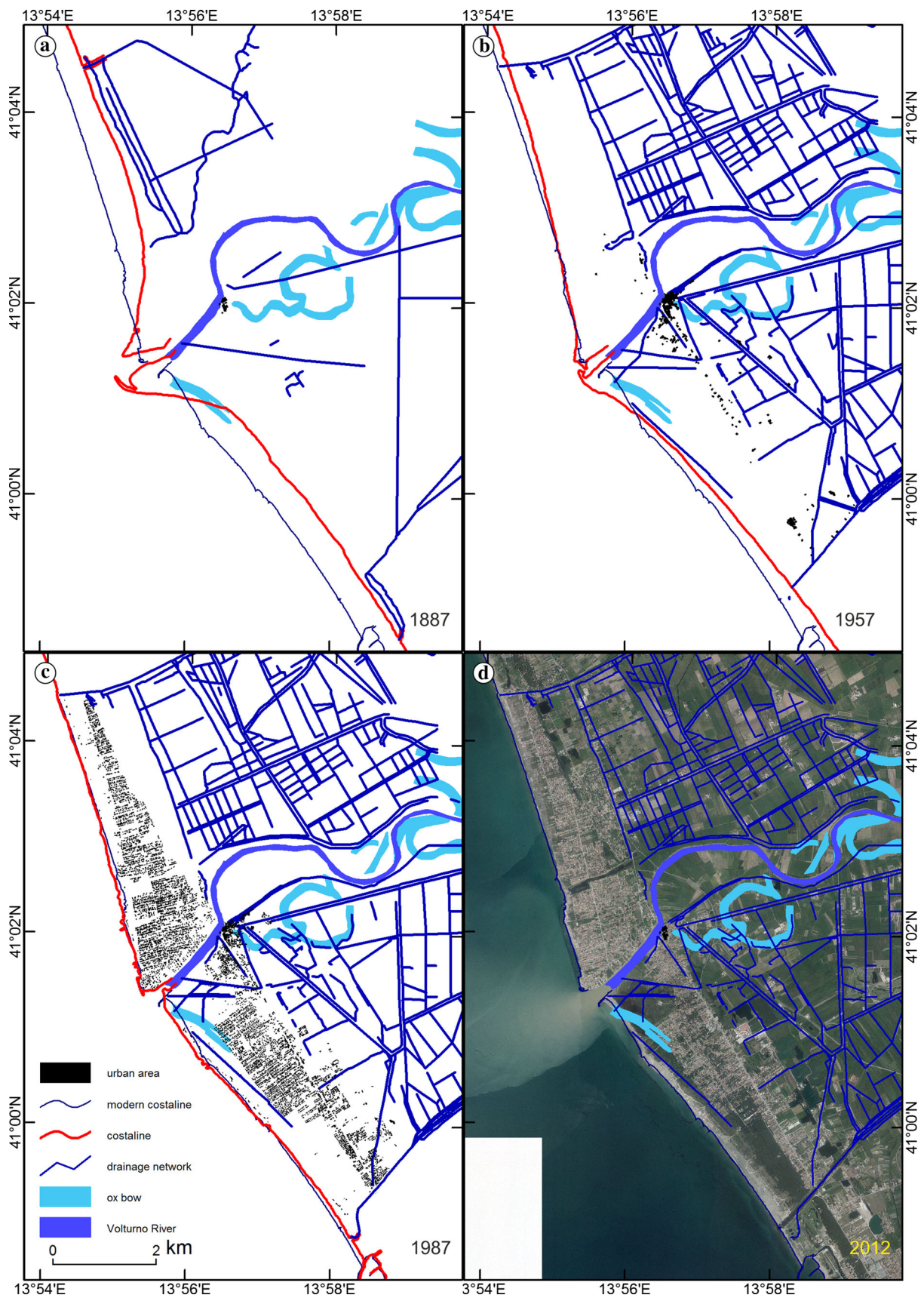


Table 4 Analysis of the drainage network characteristics through time (based on Horton 1932, 1945)

Year	Total stream	Total stream length (km)	Area (km ²)	Drainage density (km/km ²) (Horton 1932)	Stream frequency (Horton 1945)
1887	89	125.916	99.812	1.26	0.89
1957	1338	525.054	103.986	5.05	12.87
1987	1223	489.579	103.218	4.74	11.85

cover types, which have significantly reduced over the time, notably during the transition from 1957 to 1990 (− 5.3, − 1.7 to 2.6%, respectively). This trend continued in the subsequent period (1990–2012) but with less sharp decreases. Fruit cultivation increased in the first period and then reduced significantly; greenhouses appear only in the interval 1990–2012 (1.0%). A reduction in beach-dune land was recorded up to 1990. The artificial surfaces were the land use type with the largest rate of increase in the same time (+ 9.2%), passing from 0.8% (1.5 km²) of the whole area in 1957–10% (18.8 km²) in 1990; in the following years it increases with a lesser extent (5%).

Change matrices

To assess inter-conversion of different LULC classes over time, change matrices were prepared (Table 6). Over the interval 1957–1990, a sharp increase in artificial surfaces (including urban areas) was mainly covered by conversion of arable land (5.0%), sclerophyllous vegetation (1.9%) and vineyards (1.4%). From 1990 to 2012 5.8% of arable land was converted into artificial surfaces, with further minor contribution from the other land cover types. Part of the agricultural activities were converted into industrial ones (greenhouses) since the 1990s. In the coastal area, SV and WB gained little surfaces from AL and VY, whereas small transitions occurred between BD, SV and CF over the whole time period.

Landscape metrics at a class level

Landscape metrics helped in quantitative assessment of landscape structures and convey the extent of changes. In the present study, landscape metrics were performed only at class level (Table 2), because the main purpose was to highlight major changes in land uses and the extent of fragmentation.

Figure 7 shows the change in landscape metrics between 1957 and 2012. The parameter number of patches (NP) increased by over 400%, passing from 91 to 488. Patch density (PD) increased from 0.5 to 2.6 and mean patch size (MPS) decreases from 207 to 38 (Fig. 7). This clearly underlies fragmentation and increased spatial variability of the landscape.

From 1957 to 2012, at the class level both NP and PD show that the numbers of patches are increasing for all classes and a reduction in the mean patch size (MPS) is recorded for all class with the exception of coniferous forests (Fig. 7).

- **AS:** although the surfaces have increased from 1957 to 1990, the NP and PD significantly increased from 1990 to 2012, whereas MPS increased from 1957 to 1990 and then drastically decreased in the interval 1990–2012. This is explained because of all the artificial surfaces; between 57 and 90, we see the massive expansion of the urban fabric. Since the end of the 1980s, only infrastructures linked to the urban areas were built, thus justifying the subsequent MPS fall.
- **AL:** Landscape metrics showed a steady increase in NP and PD and the decrease in MPS. According to change matrices, the AL were converted into artificial areas, fragmented between them (MPS reduces).
- **FT:** NP and PD shot up from 1990 to 2012 with the collapse of MPS. The surfaces increased from 1957 to 1990 but then decreased (almost halved) strongly in 2012 losing ground in AL, AS, GH and VY.
- **VY:** NP and PD decreased (halved) in 57–90 and also diminish the areas occupied by this land use type. Because MPS decreased as well (but to a lesser extent), it is to assume that disappeared whole plots of land, instead of experiencing a fragmentation. Since VY were widespread especially in coastal areas behind the dunes, in that interval they gave land to AS and AL close to them. Between 1990 and 2012, there was a rather sharp increase in NP and PD with a significant drop of MPS and the surfaces, reflecting instead a large fragmentation of the residues patches that became small and scattered.
- **SV:** SV shows minimal variations of NP and PD between 1957 and 1990 although MPS decreased along with the total of the areas occupied. From 1990 to 2012 the trend reversed: NP and PD almost tripled and MPS collapsed. The decrease in the total area was not so strong, so it is likely that the creation of the accompanying infrastructure to urban expansion has contributed to fragment the patches.

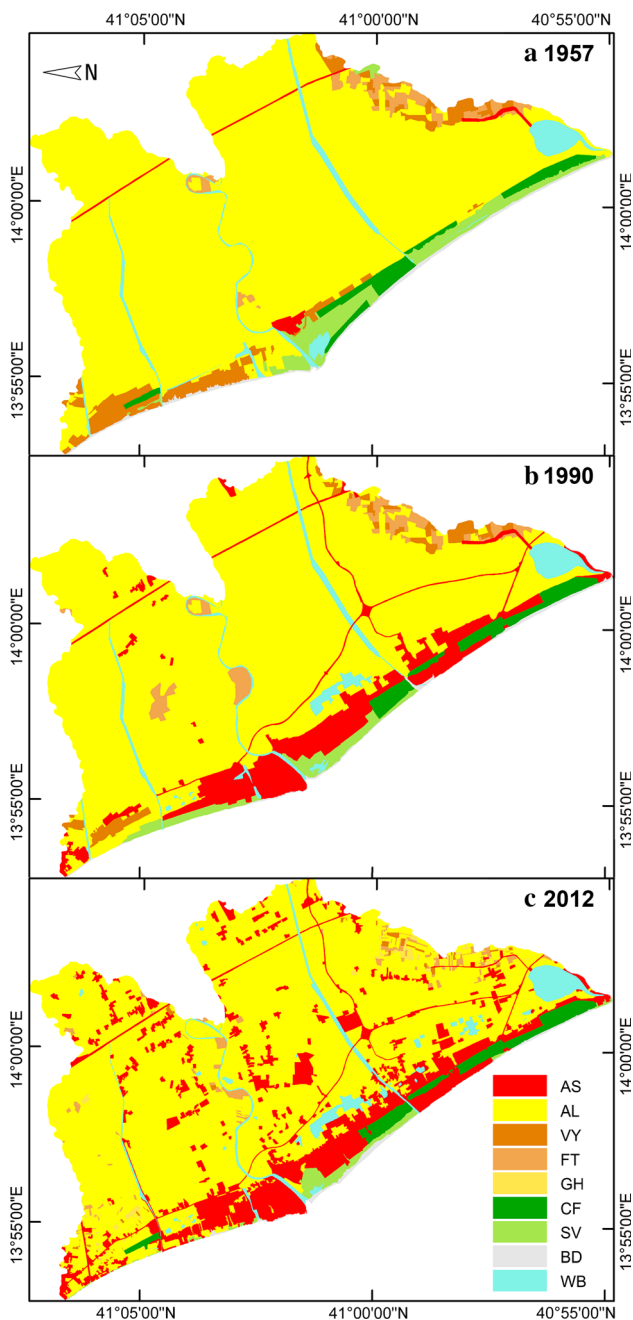


Fig. 6 Land use/land cover maps of the coastal plain around the Volturno delta in 1957, 1990, 2012. It is noteworthy the increase through time of built-up land areas closely spaced with the humid, lacustrine/marshy back-dune areas and also the urban area overgrowing to the sea, with loss of the beach-dune system. Area statistics and LULC change rates are shown in Table 5

- **CF:** NP and PD were constant over time although MPS increased dramatically between 1957 and 1990 before decreasing in 2012. The total area decreased slightly until 1990, shifting to SV, AS and AL. The collapse of MPS from 1990 onwards, however, combined with the recovery of the total areas lost in the previous period,

suggests that the protection and conservation of this environment, which is also state-owned, allowed it to gain surfaces mainly by AL, AS and SV, although the creation of access infrastructure to the sea in built-up areas induced a fragmentation of patches (loss of continuity).

- **BD–WB:** NP and PD were constant between 1957 and 1990 even if the MPS decreased with a minimum loss of BD surfaces. Between 1990 and 2012, NP and PD increased exponentially with the collapse of MPS. This is linked to urbanization as well as to geomorphological dynamics of the whole coast and the delta of the Volturno. The increase in NP was also due to the growth of small artificial lakes/ponds in abandoned sand pits.

The observed increase in the number of patches and decrease in mean patch size is consistent with the increase in the number of contacts between the land use polygons (Table 7). These changes are representative of a more isolated and fragmented landscape.

Discussion

Drainage network and coastline changes

As previously mentioned, the first reclamation work consisted in the canalization of the Clanio River that was diverted directly into the Tyrrhenian Sea across the dune system (Fig. 2); only a small channel (Vena Channel) remained as an inflow into the Patria Lake. One of the first morphological variations associated with the canalization was the reduction in the extent of the former lagoon area that progressively shrunk during the last three centuries to the present-day size of the Patria Lake (Fiengo 1988; Sacchi et al. 2014; Fig. 8).

North of the Volturno River, marshy areas were widespread as well, as the channels were naturally diverted along the shoreline, probably behind a well-developed dune system (e.g. the Savone River—*Saone f.*—flowing directly into the *Pantano*—marsh—*di Mondragone*; Figs. 2, 4a). The final stretch of the Savone was canalized and diverted across the dune system to drain the marshes. Between the Savone and Volturno rivers, a canal system was created to dry the *Pantano di Capua* (Marsh of Capua), first, and afterwards to catch the Agnena Canal (Fig. 2). As a result of the whole interventions, only few remains of the previous marshy–lagoon areas were preserved along the coast, the largest of which is nowadays located south of the Volturno Delta, characterized by small ponds, sites of community importance and protected in the frame of Natura 2000 network (Variconi Oasis, Fig. 1).

Table 5 Land use/land cover area statistics and rate of land use/land cover changes. LULC maps in Fig. 6

LULC	1957		1990		2012		Change 1957–1990		Change 1990–2012	
	km ²	%	km ²	%	km ²	%	km ²	%	km ²	%
AL	153.3	81.3	143.4	76.0	137.7	73.1	− 9.9	− 5.3	− 5.7	− 2.9
AS	1.5	0.8	18.8	10.0	28.2	15.0	17.3	9.2	9.4	5.0
BD	2.5	1.3	1.9	1.0	2.0	1.1	− 0.6	− 0.3	0.1	0.1
CF	4.5	2.4	4.2	2.2	4.5	2.4	− 0.3	− 0.1	0.3	0.2
FT	3.9	2.1	5.1	2.7	2.7	1.4	1.1	0.6	− 2.4	− 1.3
GH					1.8	1.0			1.8	1.0
SV	7.0	3.7	3.7	2.0	2.4	1.2	− 3.3	− 1.7	− 1.4	− 0.7
VY	8.4	4.5	3.6	1.9	0.7	0.4	− 4.8	− 2.6	− 2.9	− 1.5
WB	7.5	4.0	8.0	4.2	8.4	4.5	0.5	0.3	0.4	0.2

The extent of such a reclamation intervention is quantified in more than 500 km of canals (Table 4), with an average drainage density of about 5 km/km² up to the first half of the 1900. In the following years, the extent of the drainage structure remained fairly constant, but some water flow infrastructures have been progressively removed or destroyed.

Although the creation of a drainage system had a key role in landscape transformation and agricultural development, very often the increase in urbanization and the related land use changes resulted in drainage network alteration in most of the countries that faced landscape reclamation in Europe as in other temperate estuarine and coastal systems (e.g. Healy and Hickey 2002; Lotze et al. 2006; Earle and Doyle 2008; Salvati et al. 2013; Di Giuseppe et al. 2014; Sofia et al. 2014). All this had a negative effect on the state of health of the drainage system itself which resulted in a loss of storage capacity of the drainage system and a consequent increase in flood risk.

In addition to the problems listed above, the changes in drainage pattern included the issues of shoreline erosion and sea defence, as they were considered the main cause of reduction in sediment supply to most Mediterranean coast resulting in severe effects on many deltas and adjacent shorelines (e.g. Surian and Rinaldi 2003; Hooke 2006; Wohl 2006; Hoffmann et al. 2010; Anthony et al. 2014; Pranzini et al. 2015).

With respect to this latter point, along the studied littoral a strong coastline retreat has been documented since the beginning of 1900 (Fig. 5), following not only reclamation but also other interventions along the Volturno River course (dams, sand excavations, among others; De Pippo et al. 2008; Ruberti et al., 2008; Verde et al., 2013). In the first half of the last century, the delta mouth triangle was eroded and sediments from the cusped delta apex were deposited along the lee-side, resulting in a progradation of the coastline (Fig. 5a, b); after the complete dismantling of

the delta body, the shoreline became rectified (Fig. 5c) and an overall retreat was recorded (Fig. 5d); the Volturno Delta became an estuary. Most of the buildings built close to the beach were seriously damaged or destroyed by the coastal retreat.

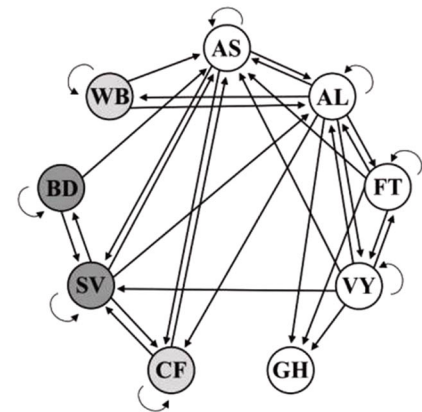
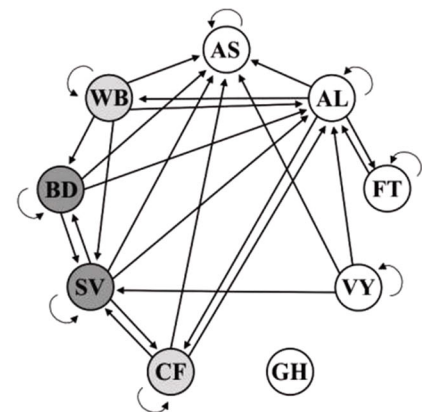
Coastal erosion has been regarded as one of the causes of increase in the vulnerability of coasts and deltas to potential influence of waves, in the face of sea level rise associated with climate changes (e.g. Ericson et al. 2006; Lambeck et al. 2011; Fletcher and Zielhofer 2013; Maselink and Gehrels 2014). The effects associated with the rising of sea level are also amplified in those countries affected by subsidence (Higgins 2016). Most of the Mediterranean alluvial coastal plains are subsiding and significant subsidence was assessed also in Italy, above all in the Po and Sele plains (Tosi et al. 2013; Pappone et al. 2012). Nevertheless, more recently high negative values of ground deformation (up to—35 mm/year) were detected in the Volturno plain by analysing LiDAR data of the Italian Environmental Ministry (Matano et al. 2016); by comparing sea level rise forecasts and subsidence trends, Aucelli et al. (2016) elaborated risk inundation maps, posing important constraints in the future management of the coastal plain.

Unfortunately, in the last decades, the absence of a sustainable management policy has led to the realization of uncoordinated interventions to mitigate the effects of erosion. Coastal engineering, developed both for protection uses and commercial, industrial or touristic purposes, has completely transformed the original shore type and morphology since the 1970s (De Pippo et al. 2008; Anthony et al. 2014; Pranzini et al. 2015; Di Natale et al. 2017). Of particular impact were groins and breakwaters, constructed to reduce the incoming coastal erosion; following “hot-spot” mitigation interventions, they had often the effect of worsening the situation or generating damages downdrift from the structures (Pranzini et al. 2015).

Table 6 Change matrices for 1957–1990 and 1990–2012 (area %)

	AL	AS	BD	CF	FT	GH	SV	VY	WB	% 1957
AL	74.6	5.0		0.1	1.0				0.8	81.6
AS		0.8								0.8
BD	0.1	0.1	0.5				0.5			1.2
CF	0.2	0.6		1.3			0.2			2.4
FT	0.4				1.7					2.1
GH										
SV	0.1	1.9	0.1	0.9			0.6			3.6
VY	0.8	1.4					0.5	1.8		4.5
WB	0.1	0.2	0.1				0.2		3.4	3.9
% 1990	76.3	10.0	0.7	2.2	2.7		2.0	1.9	4.2	100

	AL	AS	BD	CF	FT	GH	SV	VY	WB	% 1990
AL	67.8	5.8		0.2	0.8	0.6		0.2	0.9	76.2
AS	1.0	8.5		0.2			0.2			10.0
BD		0.1	0.5				0.1			0.8
CF		0.1		2.0			0.2			2.2
FT	2.0	0.1			0.4	0.2		0.1		2.7
GH										
SV	0.6	0.2	0.3	0.1			0.8			1.9
VY	1.3	0.1			0.2	0.2		0.1		1.9
WB	0.5	0.2							3.5	4.2
% 2012	73.3	15.0	0.9	2.4	1.4	1.0	1.2	0.4	4.5	100.0



Each row indicates the area percentage of a given LU category that was transformed in other LU types at the end of the time interval. Grey cells correspond to area percentages which did not change. Key as in Table 2. A graphical representation of the changes is shown on the right. Arrows indicate trajectories of transformations; circular arrows indicate land use types that preserve a certain percentage of surface in the same utilization. Dark grey: landscape elements of high ecological quality; light grey: landscape elements of medium ecological quality; white: landscape elements of low ecological quality (see text for further explanations)

Bold values represent the sum percentage area of each LULC category in each reference year

LULC changes and their impact on coastal habitats

The availability of reclaimed land along the Volturno coastal plain fostered the development of agriculture and farming (Fig. 5d). The local economy thus shifted from subsistence agriculture to industrial agro-systems. As a consequence, the landscape changed, resulting in a patchwork of medium-to-small-sized productive activities with dense hedgerows and canals, with dispersed, more intense urban areas.

On the whole, the first major changes in land cover occurred between 1800 and 1950, with conversion of most

salt marshes and coastal/marine areas into croplands and/or grassland. Between 1950 and 1980, a massive urbanization of the coastal area replaced most of the former land cover types, as evidenced in Fig. 6. Built-up land area increased in this time interval and urban area overgrew to the sea (Fig. 5, 6). Only in the coastal setting, around the mouth of the Volturno River, there was a considerable increase in built in just over a decade. From 1980s onwards, the changes in the urban fabric were minimal, presumably due to territorial saturation and further growth was restricted to scattered urban agglomerations.

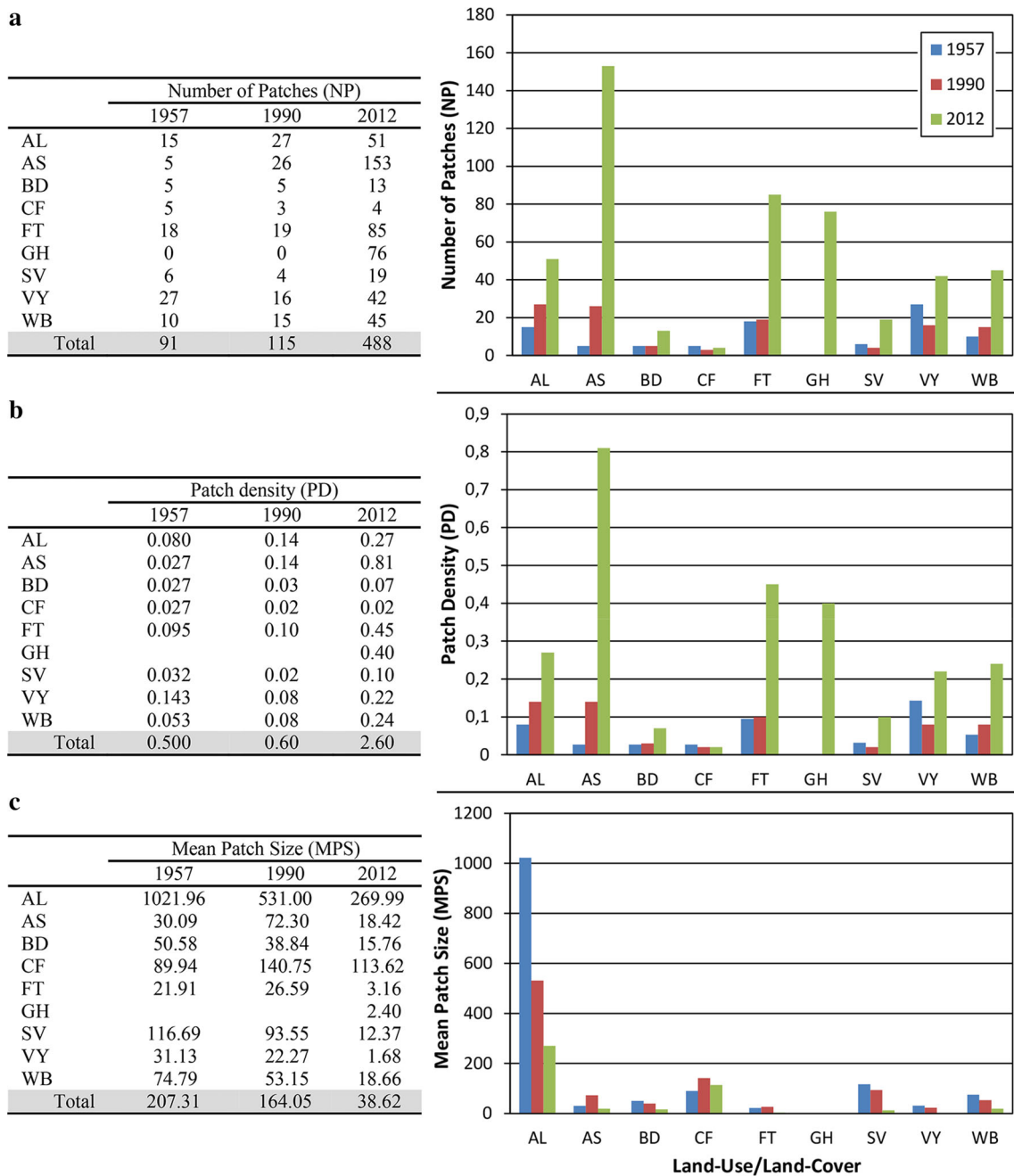


Fig. 7 Graphical representation of the changes in landscape pattern metrics among the different LULC types in 1957 1990 and 2012. **a** number of patches; **b** patch density; **c** mean patch size

Considering the change matrices (Table 6), a conspicuous fraction of agricultural land and minor natural landscape (beach-dune and associated vegetation) have been converted into settlement areas to support the increasing request of built-ups. Trajectory and pattern analysis showed that the landscape have undergone high fragmentation and increased spatial variability (Fig. 7). Sclerophyllous vegetation reduced in area e MPS up to 1990, due to the great urban explosion with the use of these portions of land for summer residential, often

illegal, buildings. The erosion of the coast caused the retreat of the beach-dune system which incorporated part of SV and forced its conversion in adjoining LULC types. Wetlands were mainly converted to urban areas and cropland but suffered also the shoreline retreat. After this time, the creation of all the accompanying infrastructure to urban expansion has contributed to further fragment the territory. Also the coniferous forest close to the SV lost their continuity owing to the creation of access infrastructure to the sea in built-up areas.

Table 7 Number of contacts between the different LULC types in the different time period considered. Key as in Table 2

LULC	AL	AS	BD	CF	FT	GH	SV	VY	WB
<i>1957</i>									
AL									
AS	10								
BD	4								
CF	4		2						
FT	16	5							
GH									
SV	4	1	4	4	2				
VY	26	6	5	4	19		6		
WB	19	5	10	4	3		7	10	
<i>1990</i>									
AL									
AS	45								
BD	2	7							
CF	3	5	2						
FT	22	6							
GH									
SV	2	4	4	1					
VY	22	5			21				
WB	25	17	7		2		5	2	
<i>2012</i>									
AL									
AS	196								
BD	5	18							
CF	1	6	1						
FT	88	34							
GH	81	18		1	37				
SV	15	21	19	3					
VY	47	12			18	22			
WB	58	36	10	2	8		6		

Graphs in Table 6 highlight the trajectories of the above transformation. All agricultural land uses types were fragmented over time, giving rise to small scattered polygons between artificial areas (mostly urban settlements). Some of them, from the 1990s, are transformed into industrial crops, as evidenced by their conversion in greenhouses. To emphasize this fragmentation are the increase in NP and PD and the MPS decrease. It is noteworthy the disappearance of the vineyards along the coast whose soils were occupied by housing surfaces or were transformed into arable lands. In this area, corresponding to the ancient *Ager Falernus*, the production of wine (*vinum Falernum*) was important since the time of the Romans. The crisis of traditional agriculture along the coastal areas is a common phenomenon in the Mediterranean basin (Salvati et al. 2013) that follows the concentration of economic activities

in these settings, having negative consequences on land quality.

As a mirror of conditions widespread along the Mediterranean coasts, in the Domitia Littoral the increase in built-up surfaces, often abusive and without sewage systems, as well as that of the agricultural and livestock activities, accompanied by the destruction of part of the drainage canals, determined sediment pollution and microbiological contamination of marine waters (cf. Verde et al. 2013; Balassone et al. 2016; Teta et al. 2017). In fact, the intensive uses of the reclaimed territory for agriculture and farming purposes implies large use of fertilization and chemical soil treatment; leaching of soils allows the transport of the pollutants through the drainage channels and ultimately to the sea. This trend increased in the last half century because of the overreliance to income from land released after 1950s.

Impacts from human activities are also invariably destructive to coastal ecosystems as they lead to habitat degradation and reduction in coastal biodiversity. Natural habitats have considerably decreased and fragmented as a result of reclamation of marshy areas and the introduction of novel types of land use over the floodplain and coastal areas (i.e. cultivation, farming, housing). All this resulted in the loss of high-quality ecosystems such as the humid coastal setting (protected under the European Water Framework Directive, Nature 2000 and the Ramsar Convention), the lacustrine/marshy back-dune area and, in most cases, also the beach-dune system (Fig. 5d). Moreover, landscape fragmentation also resulted in increased contact between “landscape elements of high and medium ecological quality” (“habitats”), such as wetlands, rivers and beach-dunes, and “landscape elements of low ecological value” (“barriers”)—such as roads, residential areas, dams and industrial complexes (cf. Kienast 1993). The interactions of a given patch with adjacent land cover types affect both land use exploitation by humans and vegetation dynamics (Smiraglia et al. 2007).

Table 7 highlights the increase in number of the above contacts over time between landscape elements of very different ecological quality (e.g. SV vs. AS), in the territory studied. All of the so-called barriers appear closely spaced with small wetland remains, the beach-dune system and the related vegetation. Comparing the whole set of results obtained (Fig. 7, Tables 5, 6 and 7), these changes are representative of a more isolated and fragmented landscape (increase in NP and decrease in MPS) that results in the interruption of connectivity. From the point of view of the prediction of the ecological effects of landscape changes, the integration of such multi-temporal analyses makes the ecological assessment possible and allows a better land planning and natural resources management, although beyond the scope of the present paper.



Fig. 8 Evolution of the coastal lake “Lago Patria” following the land reclamation. **a** Close-up of the “Campania” map painted on the Vatican Museum (1580–1585). South of the Volturno River the large lagoon Lake Patria is shown as an embayment semi-enclosed by a spit. **b** The historical topographic map by Magini (1620) shows a large lagoonal area (*Lago di Patria*) fed by the Clanio river (to north) and opened to the sea in its southern part. The reduction in the lake extension after the Clanio canalization was reconstructed with a cartographic overlay (**c**); note also the position of the outlet that shifted southwards under the action littoral drift since the first half of the last century, after which was channelled

Coastal socio-economic developments associated with land reclamation can thus be considered the main drivers of the destruction of ecosystem functions in this coastal setting, shifting vegetated wetlands to lands used for agriculture and urbanization. The reduction in wetlands increases in turn the vulnerability of human settlements to climate change because coastal wetlands act as natural buffers to reduce wave action and shoreline erosion, and to attenuate storm surges (Wolanski et al. 2009; Barbier et al. 2011; Arkema et al. 2013; Tian et al. 2016; Zhu et al. 2016a), especially in coastal settings also affected by severe erosion.

Although it is difficult and challenging to rehabilitate coastal wetlands that have been converted for urban and industrial development land use, the use of landscape metrics brought insights in the extent of the coastal changes in order to inform restoration planning, in the view of a predicted sea level rise (Lambeck et al. 2011).

Summary and conclusions

Driven by land reclamation, over the last 100 years the northern Campania Plain has experienced rapid economic development and urbanization growth which resulted in significant landscape changes, loss of coastal wetland, coastal erosion and degradation of marine ecosystem.

By combining historical with the topological analysis, the present study investigated the long-term impact of anthropogenic activities on the geomorphology and hydrology of the alluvial plain during the last 150 years. The accuracy of the digitized maps allowed the realization of reliable map products.

Landscape metrics allowed to assess and quantify major land use dynamics and landscape pattern changes over the last 100 years, highlighting the relationships between land reclamation, urbanization growth and land use changes.

The main landscape composition went through major changes up to the beginning of 1900s, when land reclamation works completed the canalization of most secondary streams in the lower alluvial plain. The regulation of river floodplain stimulated agriculture and farming

which were major determinants of changes in landscape pattern.

Landscape fragmentation and landscape complexity increased between the 1960s and the 1990s. Since the 1970s the built-up land expanded at an accelerated rate along the coastal plain, at the expenses of the beach-dune system, and along the river course. The negative sedimentary budget deriving from the reclaiming actions on the river courses, together with the interventions along the Volturno River catchment, resulted in accelerated, severe coastal erosion.

The overgrowth of the urban areas to the sea, coupled with intensification of agricultural and tourism activities, resulted in the loss of high-quality ecosystems such as the humid coastal setting, the lacustrine/marshy back-dune area and, in most cases, also the beach-dune system in a fluvio-deltaic Natura 2000 network site in northern Campania.

The integration of landscape analysis and historical information highlights the importance of an interdisciplinary approach in land management and linked a local case study to a more general and large-scale landscape change trajectories of Mediterranean and European coastal settings. The recorded causes of past change highlight priority targets for ecosystem-based management and marine conservation. Documentation and results achieved confirm some general conclusion and patterns observed in the European Mediterranean Basin landscape and land use changes.

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References

- Airoldi L, Beck MW (2007) Loss, status and trends for coastal marine habitats of Europe. *Oceanogr Mar Biol* 45:345–405. doi:10.1201/9781420050943.ch7
- Almeida D, Rocha J, Neto C, Arsénio P (2016) Landscape metrics applied to formerly reclaimed saltmarshes: A tool to evaluate ecosystem services? *Estuar Coast Shelf Sci* 181:100–113. doi:10.1016/j.ecss.2016.08.020
- Amorosi A, Pacifico A, Rossi V, Ruberti D (2012) Late Quaternary incision and deposition in an active volcanic setting: the Volturno valley fill, southern Italy. *Sed Geol* 282:307–320. doi:10.1016/j.sedgeo.2012.10.003
- Anthony EJ, Marriner N, Morhange C (2014) Human influence and the changing geomorphology of Mediterranean deltas and coasts over the last 6000 years: From progradation to destruction phase? *Earth-Sci Rev* 139:336–361. doi:10.1016/j.earscirev.2014.10.003
- Arkema KK, Guannel G, Verutes G, Wood SA, Guerry A, Ruckelshaus M, Kareiva P, Lacayo M, Silver JM (2013) Coastal

- habitats shield people and property from sea-level rise and storms. *Nat Clim Change* 3:913–918
- Aucelli PPC, Di Paola G, Incontri P, Rizzo A, Vilardo G, Benassai G, Buonocore B, Pappone G (2016) Coastal inundation risk assessment due to subsidence and sea level rise in a Mediterranean alluvial plain (Volturno coastal plain e southern Italy). *Estuarine. Coast Shelf Sci*. doi:[10.1016/j.ecss.2016.06.017](https://doi.org/10.1016/j.ecss.2016.06.017)
- Balassone G, Aiello G, Barra D, Cappelletti P, De Bonis A, Donadio C, Guida M, Melluso L, Morra V, Parisi R, Pennetta M, Siciliano A (2016) Effects of anthropogenic activities in a Mediterranean coastland: the case study of the Falerno-Domitio littoral in Campania, Tyrrhenian Sea (southern Italy). *Mar Pollut Bull* 112:271–290
- Barbier E, Hacker S, Kennedy C, Koch E, Stier A, Silliman B (2011) The value of estuarine and coastal ecosystem services. *Ecol Monogr* 81(2):169–193
- Carter RWG, Woodroffe CD (1994) Coastal evolution: an introduction. In: Carter RWG, Woodroffe CD (eds) *Coastal evolution—late Quarternary shoreline morphodynamics*. Cambridge University Press, Cambridge, pp 1–31
- De Pippo T, Donadio C, Pennetta M, Petrosino C, Terlizzi F, Valente A (2008) Coastal hazard assessment and mapping in Northern Campania, Italy. *Geomorphology* 97:451–466
- Di Giuseppe D, Faccini B, Mastrocicco M, Colombani N, Coltorti M (2014) Reclamation influence and background geochemistry of neutral saline soils in the Po River Delta Plain (northern Italy) *Environ. Earth Sci* 72:2457–2473. doi:[10.1007/s12665-014-3154-4](https://doi.org/10.1007/s12665-014-3154-4)
- Di Natale M, Di Ronza C, Eramo S, Vigliotti M, Ruberti D (2017) A sediment trap to mitigate port silting due to longshore transport. The case of Pinetamare Marina (Southern Italy). *J Coast Conserv*. doi:[10.1007/s11852-017-0538-0](https://doi.org/10.1007/s11852-017-0538-0)
- Earle T, Doyle D (2008) The engineered landscapes of irrigation. In: Cliggett L, Pool CA (eds) *Economies and Transformation of Landscape*. Altamira Press, Lanham, pp 19–46
- Ericson JP, Vörösmarty CJ, Dingman SL, Ward LG, Meybeck M (2006) Effective sealevel rise and deltas: causes of change and human dimension implications. *Glob Planet Change* 50:63–82
- Fan Q, Ding S (2016) Landscape pattern changes at a county scale: a case study in Fengqui, Henan Province, China from 1990 to 2013. *CATENA* 137:152–160. doi:[10.1016/j.catena.2015.09.012](https://doi.org/10.1016/j.catena.2015.09.012)
- Fiengo G (1988) I Regi Lagni e la bonifica della Campania Felix durante il Viceregnò spagnolo. Leo S, Olschki Editore
- Fletcher WJ, Zielhofer C (2013) Fragility of western Mediterranean landscapes during Holocene rapid climate changes. *CATENA* 103:16–29
- Healy MG, Hickey KR (2002) Historic land reclamation in the intertidal wetlands of the Shannon estuary, western Ireland. *J Coast Res* 36:365–373
- Hernández A, Miranda MD, Arellano EC, Dobbs C (2016) Landscape trajectories and their effect on fragmentation for a Mediterranean semi-arid ecosystem in Central Chile. *J Arid Environ* 127:74–81. doi:[10.1016/j.jaridenv.2015.10.004](https://doi.org/10.1016/j.jaridenv.2015.10.004)
- Higgins SA (2016) Review: advances in delta-subsidence research using satellite methods. *Hydrogeol J* 24:587–600. doi:[10.1007/s10040-015-1330-6](https://doi.org/10.1007/s10040-015-1330-6)
- Hinrichsen D (1998) *Coastal waters of the world: trends, threats and strategies*. Island Press, Washington, p 276
- Hoffmann T, Thorndycraft VR, Brown AG, Coulthard TJ, Damnati B, Kale VS, Middelkoop H, Notebaert B, Walling DE (2010) Human impact on fluvial regimes and sediment flux during the Holocene: review and future research agenda. *Glob Planet Change* 72:87–98
- Hooke JM (2006) Human impacts on fluvial systems in the Mediterranean region. *Geomorphology* 79:311–335
- Horton RE (1932) Drainage basin characteristics. *Trans Am Geophys Union* 13:350–361
- Horton RE (1945) Erosional development of streams and their drainage basins; hydrological approach to quantitative morphology. *Geol Soc Am Bull* 56:275–370
- Jin YW, Yang W, Sun T, Yang ZF, Li M (2016) Effects of seashore reclamation activities on the health of wetland ecosystems: a case study in the Yellow River Delta, China. *Ocean Coast Manag* 123:44–52
- Kienast F (1993) Analysis of historic landscape patterns with a Geographical Information System—a methodological outline. *Landscape Ecol* 8(2):103–118
- Lambeck K, Antonioli F, Anzidei M, Ferranti L, Leoni G, Scicchitano G, Silenzi S (2011) Sea level change along the Italian coast during the Holocene and projections for the future. *Quat Int* 232:250–257
- Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH, Cooke RG, Kay MC, Kidwell SM, Kirby MX, Peterson CH, Jackson JB (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science* 312(5781):1806–1809. doi:[10.1126/science.1128035](https://doi.org/10.1126/science.1128035)
- Leuven RSEW, Poudevigne I (2002) Riverine landscape dynamics and ecological risk assessment. *Freshw Biol* 47:845–865. doi:[10.1046/j.1365-2427.2002.00918.x](https://doi.org/10.1046/j.1365-2427.2002.00918.x)
- Li Y, Shi Y, Zhu X, Cao H, Yu T (2014) Coastal wetland loss and environmental change due to rapidurban expansion in Lianyungang, Jiangsu, China. *Reg Environ Change* 14:1175–1188. doi:[10.1007/s10113-013-0552-1](https://doi.org/10.1007/s10113-013-0552-1)
- Mallinis G, Emmanoloudis D, Giannakopoulos V, Maris F, Koutsias N (2011) Mapping and interpreting historical land cover/land use changes in a Natura 2000 site using earth observational data: the case of Nestos delta, Greece. *Appl Geogr* 31:312–320. doi:[10.1016/j.apgeog.2010.07.002](https://doi.org/10.1016/j.apgeog.2010.07.002)
- Martin BA, Shao G, Swihart RK, Parker GR, Tang L (2008) Implications of shared edge length between land cover types for landscape quality: the case of Midwestern US, 1940–1998. *Landscape Ecol* 23:391–402. doi:[10.1007/s10980-008-9197-8](https://doi.org/10.1007/s10980-008-9197-8)
- Masselink G, Gehrels R (eds) (2014) *Coastal Environments and Global Change*. Wiley, New York, p 448
- Matano F, Ruberti D, Sacchi M, Vigliotti M (2016) Subsidence trends detected by SAR interferometry and buried stratigraphic architecture in a coastal plain (northern Campania, southern Italy). In: *Calcaterra Geosciences on a changing planet: learning from the past, exploring the future*. In: *Rendiconti Online della Società Geologica Italiana* 40 (1):356. ISSN:2035-8008
- McKenzie DH, Hyatt DE, McDonald VJ (1992). *Ecological indicators*, vol 2. (EPA/600/9-91/039, PB92-114131). Elsevier, New York
- Papastergiadou ES, Retalis A, Apostolakis A, Georgiadis Th (2008) Environmental monitoring of spatio-temporal changes using remote sensing and GIS in a Mediterranean Wetland of northern Greece. *Water Resour Manag* 22:579–594. doi:[10.1007/s11269-007-9179-7](https://doi.org/10.1007/s11269-007-9179-7)
- Pappone G, Aucelli PPC, Alberico I, Amato V, Antonioli F, Cesarano M, Di Paola G, Pelosi N (2012) Relative sea-level rise and marine erosion and inundation in the Sele River coastal plain (Southern Italy): scenarios for the next century. *Rend Lincei* 23:121–129
- Perry MT, Selig ER, Spalding M, Steneck R, Watson R (2008) A global map of human impact on marine ecosystems. *Science* 319(5865):948–952
- Pranzini E, Wetzel L, Williams AT (2015) Aspects of coastal erosion and protection in Europe. *Journal of Coastal Conservation* 19:445–459
- Roebeling PC, Costa L, Magalhaes-Filho L, Tekken V (2013) Ecosystem service value losses from coastal erosion in Europe:

- historical trends and future projections. *J. Coast. Conser.* 17(3):389–395. doi:[10.1007/s11852-013-0235-6](https://doi.org/10.1007/s11852-013-0235-6)
- Ruberti D, Strumia S, Vigliotti M, D’Ambra G, D’Angelo C, Verde R, Palumbo L (2008) La gestione integrata della fascia costiera: un’applicazione al litorale Domitio, in provincia di Caserta. *Atti del Convegno Nazionale “Coste Prevenire, Programmare, Pianificare”*. Studi e ricerche della collana dell’Autorità di Bacino della Basilicata, 15–17 maggio 2008 Maratea 9:309–319
- Sacchi M, Molisso F, Pacifico A, Vigliotti M, Sabbarese C, Ruberti D (2014) Late-Holocene to recent evolution of Lake Patria, South Italy: an example of a coastal lagoon within a Mediterranean delta system. *Global Planet Change* 117:9–27. doi:[10.1016/j.gloplacha.2014.03.004](https://doi.org/10.1016/j.gloplacha.2014.03.004)
- Salomons W, Turner K (2005) Catchment-coastal region research. *Reg Environ Change* 5:50–53. doi:[10.1007/s10113-004-0067-x](https://doi.org/10.1007/s10113-004-0067-x)
- Salvati L, Tombolini I, Perini L, Ferrara A (2013) Landscape changes and environmental quality: the evolution of land vulnerability and potential resilience to degradation in Italy. *Reg Environ Change* 13:1223–1233. doi:[10.1007/s10113-013-0437-3](https://doi.org/10.1007/s10113-013-0437-3)
- Smiraglia D, Zavattero L, Ricotta C, Blasi C (2007) The use of adjacency analysis for quantifying landscape changes. *Plant Biosyst* 141(3):384–389. doi:[10.1080/11263500701627752](https://doi.org/10.1080/11263500701627752)
- Sofia G, Prosdocimi M, Dalla Fontana G, Tarolli P (2014) Modification of artificial drainage networks during the past half-century: evidence and effects in a reclamation area in the Veneto floodplain (Italy). *Anthropocene* 6:48–62. doi:[10.1016/j.ancene.2014.06.005](https://doi.org/10.1016/j.ancene.2014.06.005)
- Strabone (2007) *Geografia. L’Italia*. (Libri V–VI). A cura di Biraschi A.M. (Sesta Ed.), RCS Rizzoli Libri S.p.A., Milano
- Surian N, Rinaldi M (2003) Morphological response to river engineering and management in alluvial channels in Italy. *Geomorphology* 50:307–326
- Teta R, Romano V, Della Sala G, Picchio S, De Sterlich C, Mangoni A, Di Tullio G, Costantino V, Lega M (2017) Cyanobacteria as indicators of water quality in Campania coasts, Italy: a monitoring strategy combining remote/proximal sensing and in situ data. *Environ Res Lett.* doi:[10.1088/1748-9326/aa5649](https://doi.org/10.1088/1748-9326/aa5649)
- Tian B, WuWT Yang ZQ, Zhou YX (2016) Drivers, trends, and potential impacts of long-term coastal reclamation in China from 1985 to 2010. *Estuar Coast Shelf Sci* 170:83–90
- Tosi L, Teatini P, Strozzi T (2013) Natural versus Anthropogenic Subsidence of Venice. *Sci Rep.* doi:[10.1038/srep02710](https://doi.org/10.1038/srep02710)
- Varga K, Dévai G, Tothmérész B (2013) Land use history of a floodplain area during the last 200 years in the Upper-Tisza region (Hungary). *Reg Environ Change* 13:1109–1118. doi:[10.1007/s10113-013-0424-8](https://doi.org/10.1007/s10113-013-0424-8)
- Verde R, Vigliotti M, Prevedello L, Sprovieri M, Ruberti D (2013) An integrated approach to environmental quality assessment in a coastal setting in Campania (Southern Italy). *Environ Earth Sci* 70(1):407–424. doi:[10.1007/s12665-012-2136-7](https://doi.org/10.1007/s12665-012-2136-7)
- Viparelli C (1965) Sistemazione dell’opera di foce dei Regi Lagni. *Atti IX Convegno di Idraulica e Costruzioni idrauliche*, Trieste, maggio 1965:1–8
- Walsh K (2013) *The archaeology of mediterranean landscapes: human-environment interaction from the Neolithic to the Roman period*. Cambridge University Press, Cambridge
- Ward JV, Tockner K, Arscott DB, Claret C (2002) Riverine landscape diversity. *Freshw Biol* 47:517–539. doi:[10.1046/j.1365-2427.2002.00893.x](https://doi.org/10.1046/j.1365-2427.2002.00893.x)
- Wohl E (2006) Human impacts to mountain streams. *Geomorphology* 79:217–248
- Wolanski E, Brinson MM, Cahoon DR, Perillo GME (2009) Coastal Wetlands: a synthesis. In: Perillo GME et al (eds) *Coastal Wetlands: an integrated ecosystem approach*. Elsevier, ISBN: 978-0-444-53103-2, Chapter 1: 1-62
- Zhu G, Xie Z, Xu X, Ma Z, Wu Y (2016a) The landscape change and theory of orderly reclamation sea based on coastal management in rapid industrialization area in Bohai Bay, China. *Ocean Coast Manag* 133:128–137. doi:[10.1016/j.ocecoaman.2016.09.016](https://doi.org/10.1016/j.ocecoaman.2016.09.016)
- Zhu MS, Sun T, Shao DD (2016b) Impact of land reclamation on the evolution of shoreline change and nearshore vegetation distribution in Yangtze river estuary. *Wetlands*. doi:[10.1007/s13157-014-0610-6](https://doi.org/10.1007/s13157-014-0610-6)

Cartography

- Compagnia Generale Riprese Aeree S.p.A.© (2012) “TerraItaly™ NR”. Digital copies of aerial photographs, Parma (Italy)
- De L’Isle G (1711) *Regionum Italiae mediarum tabula geographica*. Roma
- De Silva FC (1692) *Campagna Felice*. Antonio Bulifon (ed), Napoli
- IGM (1876) *Carta dell’Italia meridionale—Foglio 52 (Parte Occidentale)—Capua*. Istituto Geografico Militare Italiano, Firenze
- IGM (1887) *Carta d’Italia. Foglio 171 II Mondragone*. Firenze
- IGM (1957) *Carta Topografica d’Italia. Fogli 171 II NE (Mondragone), 171 II SE (Castelvoturno), 184 II NO (Lago di Patria), 172 III NO (S. Andrea), 172 III SO (Villa Literno)*. Istituto Geografico Militare Italiano, Firenze
- Magini GA (1620) *Terra di Lavoro olim Campania felix*. Bologna
- Regione Campania (1987) *Carta Topografica Programmatica Regionale della Campania. Tav. 14 (Mondragone), Tav. 15 (Grazzanise), Tav. 22 (Lago Patria)*. Regione Campania, Selca, Firenze
- Zerbi D (2003) *La Carta Austriaca del Regno di Napoli*. Based on Rizzi-Zannoni “Atlante del Regno di Napoli”; Ed. Monteleone D., Vivo Valentia
- www.sinanet.isprambiente.it/it/sia-ispra/download-mais/corine-land-cover/corine-land-cover