



Coastalization patterns in the Mediterranean: a spatiotemporal analysis of coastal urban sprawl in tourism destination areas

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Abstract Under the current climate change scenery, coastalization, i.e. a linear-type of urban sprawl along the coastal zone, has become a key planning and policy concern at a global scale. Such a coastal urban sprawl trend seems to be further intensifying by, among others, mass tourism development in coastal destinations. This is evident by the abundance of relevant examples, being detected, among others, in the Mediterranean region. Taking into consideration the extreme pressure of the coastalization trend on land/marine ecosystems and its impacts on sustainability and resilience objectives, the focus of this research is on the development of a spatiotemporal and data-driven methodological approach that is capable of quantifying the dynamics of coastal urban sprawl. The proposed approach is grounded on a set of spatial metrics and a combination of the multitemporal Global Human Settlement Layer and the Corine Land Cover data; and is tested in four Mediterranean highly-rated tourism destinations in Spain, France, Italy and Greece. The variation of spatial metrics along different time spots and distinct distance buffers from the coast, unveils diversifying coastalization

typologies and urban sprawl patterns; and provides input for more informed and place-based policy decisions on sustainable coastal land management. The proposed approach is easily replicable to other coastal regions as well for capturing/quantifying aspects of urban sprawl and coastalization dynamics and supporting relevant evidence-based decision-making.

Keywords Mediterranean region · Coastalization · Urban sprawl · Tourism development · Spatial metrics · Spatiotemporal analysis

Introduction

Coastal zones are perceived as extremely attractive locations for human habitation and hosts of a range of socio-economic and commercial activities (Agardy et al., 2005; Ramesh et al., 2015; Stratigea et al., 2017a, b; de Andrés et al., 2018; Koutsi & Stratigea, 2021). Remarkable is also the wide variety of ecosystems, accommodated in coastal zones, which are endowed with extraordinary natural richness and diversity; and are *homes* to various species and habitats (Marignani et al., 2017).

Currently, a large share of the world's population (2.4 billion or about 40%) resides within a distance of about 100 km from coast (UN, 2017). Furthermore, the majority of the world's megacities are located in the coastal neighbourhood (Brown et al., 2013; Rubiera-Morollón & Garrido-Yserte, 2020), including

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major port cities in strategic geographical locations, highly reputed and vibrant coastal tourism destinations, etc.

Despite the fact that the zone of 0–100 km is rather broad and does not always reflect the area close to the shore that is featured as "coastal zone", the aforementioned figures are indicative of the pressures exerted by socio-economic processes and human interventions on these zones. These pressures are, additionally, expected to: further escalate in the future due to the rising urbanization trends (Neumann et al., 2015); render coastal zones particularly vulnerable; and result in spatial conflicts that can place sustainability of both the natural and human ecosystems at stake (Bowen et al., 2006; Stratigea et al., 2017a, b; Huang et al., 2018; Robert et al., 2019).

But how exactly are coastal zones defined? Generally, it is recognized that the land and marine compartments in coastal zones are highly interwoven spatial entities. This is reflected in the general workable definition, adopted by the European Environment Agency (EEA, 2020). This definition claims that the coastal zone is the part of land that is affected by proximity to the sea and the part of sea that is affected by proximity to the land. United Nations' definition, as articulated in the Millennium Assessment Reports on ecosystems and their services (Agardy et al., 2005), sketches the concept of coastal zone as a combination of the distance-to-coast and elevation dimensions. In this regard, coastal zone is demarcated either by a threshold of 100 km distance from shore or as the area delimited between 50 m below mean sea level and 50 m above the high tide level. Nevertheless, it is important to underline that the coastal zone definition may vary a lot depending on the issue studied and the geography (physical as well as human) of a given area. McGranahan et al. (2007) claim that the use of distance-based measures is best suited for identifying *coastal pressures'* indicators; while elevation-based measures are best fitted to the identification of indicators that address vulnerability to hazards. Eurostat, (2011), in its glossary for statistics (<https://ec.europa.eu/eurostat/statistics-explained>), defines coastal regions as statistical regions (NUTS 3 level) that dispose one of the following attributes: (i) a border with a coastline, (ii) more than half of their population within 50 km from the coastline, or (iii) a strong maritime influence. Notable is also the definition used in support of the Integrated Coastal Zone

Management (ICZM) in the Mediterranean Region, articulated in the respective Protocol on ICZM in the Mediterranean. This defines coastal zone as "the geomorphologic area either side of the seashore in which the interaction between the marine and land parts occurs in the form of complex ecological and resource systems made up of biotic and abiotic components coexisting and interacting with human communities and relevant socioeconomic activities" (Official Journal of the European Union, 2009: 2).

Various researchers have recently coined the term *coastalization* (Cortesi et al., 1996; Lagarias & Sayas, 2018; Liziard, 2013; Mikhaylov et al., 2018; Serra et al., 2014; Voiron-Canicio, 1999) in order to express the rising concentration of population and activities in specific coastal zones. The meaning attached to this term features an intense and, usually, linear pattern of urban development along coastal zones, leading to a socio-economic and spatial polarization in respective regions, compared to the inland ones. This pattern is further intensified by tourism urbanization in coastal zones, where specific urban constellations are identified as cities created by and for tourism (Soto & Clavé, 2017). *Mass tourism*, in particular, infringes in most cases capacity constraints of coastal zones and threatens sustainability of both land and marine resources. Such a trend is noticed, for example, in Europe and is accompanied by intense land use exploitation in coastal areas. In fact, as land use scenarios demonstrate (Lavalle et al., 2011), coastal European areas will be confronted with important threats up to 2050, emanating from land use changes; while these threats are expected to further worsen due to *Climate Change* (CC) impacts, e.g. sea level rise, shoreline erosion, coastal flooding (Gibbs, 2016; Mentzafou et al., 2020; Satta et al., 2017; Stratigea et al., 2017).

According to Eurostat data (2019), northern Mediterranean is an exemplary case of heavily burdened territory due to incoming tourist flows. In fact, Mediterranean Region as a whole is perceived as a *tourism hotspot* (Simpson et al., 2008). Despite the role of tourism as a major source of growth and jobs' creation for the Mediterranean economies, however, mass tourism, accompanied by second home development, is currently perceived as a critical key driver in terms of intense coastalization, which increases vulnerability of coastal regions to CC impacts and jeopardizes

sustainability and resilience objectives of coastal areas concerned.

Historically, *coastal urbanization* in the Mediterranean has taken the form of port towns, serving intense commercial transactions through the well-established ancient sea routes (Koutsi & Stratigea, 2019). Therefore, many cities emerged as coastal metropolises in respective countries, e.g. Barcelona and Valencia in Spain; Marseille in France; Genoa, Naples and Palermo in Italy; Thessaloniki, Herakleion and Patras in Greece. However, since the late 20th century, urban growth in coastal zones is no longer restricted around the compactly built-up coastal cities. Driven by suburbanization trends, mass tourism and second-home development, *coastal urban expansion* by far exceeds local population growth in many areas (Couch et al., 2008; EEA, 2016). In some countries, the largely unplanned or poorly regulated character of settlement expansion, accompanied by the large-scale infrastructure deployment (Salvati et al., 2014) have so far been the driving forces of urban expansion and growth of the national/regional Mediterranean economies (Munoz, 2003). This is accompanied by large-scale mass tourism development, resulting in tourist accommodation, leisure facilities, and transport infrastructure deployment; and guiding a bubble in the construction/real estate sector. Based on that, some traditionally established tourism destinations are gradually transformed into metropolitan areas, such as the case of Costa Brava, close to Barcelona (Cuadrado-Ciuraneta & Durà Guimerà, 2018). Also, even in regulated countries, urban sprawl can go on because of uneven local planning practices (Prévost & Robert, 2016).

The above driving forces and ongoing processes are roughly framing the Mediterranean coastalization context, usually resulting in an excessive type of *urban sprawl*. As a result, a low-density and usually discontinuous and uncoordinated spatial form of urban development is observed, which expands towards agricultural and natural areas and poses severe threats to coastal and maritime ecosystems (Lagarias, 2011; Sohn et al., 2012). At the same time, this form consumes land and other scarce resources in a rather unsustainable way. Critics of urban sprawl have underlined its negative impacts and especially the: increasing car-dependency for transportation (Torrens & Alberti, 2000); need for expanding networks' infrastructure (Bruekner, 2001); higher rates

of energy consumption; loss of prime farmland, natural wetlands and core forest habitat; and increase of sealed surface (Hasse & Lathrop, 2003). Yet, different types of urban sprawl can be identified, on the ground of distinct morphological characteristics (Couch et al., 2008), resulting in complex spatial patterns.

The criticality of coastalization and urban sprawl impacts on the Mediterranean coastal zones underlines the necessity to evaluate/monitor their spatial evolution and dynamics. Addressing thus the spatial and temporal dynamics is crucial for: assessing the pressure exerted on coastal zones (Lagarias & Stratigea, 2021); and effectively informing policy decisions towards sustainable and resilient futures of these areas. Towards this end, *land use changes* are considered as a key issue in order for the future state of coastal zones to be assessed (Lavalley et al., 2011); while other approaches call for the development of multi-disciplinary research on urban sprawl encompassing a range of topics like land use, land ownership, landscapes, urban planning, hydrology etc. (Robert et al., 2019).

A lot of research has already been conducted in this respect, focusing on coastal urban sprawl in Mediterranean countries (Catalán et al., 2008; Garcia-Palomares, 2010; Hennig et al., 2015; Lagarias & Sayas, 2018; Pardo-García & Mérida-Rodríguez, 2018; Romano & Zullo, 2014; Salvati & De Rosa, 2014; Salvati et al., 2012, 2013; Tombolini et al., 2015). However, comparative studies that illuminate urban sprawl processes in coastal areas in the Mediterranean are sparse (Cori, 1999). That said, the *scope* of this paper is to fill this gap, having as a *research target* to analyze the diversity and dynamics of coastalization patterns in Mediterranean coastal tourism destination areas. A spatiotemporal approach is applied, with a focus on the combination of a set of geospatial methods and multi-temporal land use data. Methodology is grounded on a set of *spatial metrics* (Herold et al., 2003) that quantify the density, aggregation/clustering and dispersion of built-up areas. Spatial metrics are introduced in landscape ecology (Turner, 1989) as indicators representing specific landscape attributes, such as land use class, habitat type etc. According to Herold et al. (2005), spatial metrics emanate from the analysis of thematic-categorical maps that exhibit spatial heterogeneity at a specific scale and resolution, and bring out the spatial component of the urban form and the dynamics of change. In fact,

spatial metrics have been extensively used to: analyze *land use changes* (e.g. Pham et al., 2012; Ramachandra et al., 2012); assess *changes in the urban form* (e.g. Aguilera-Benavente et al., 2014); and compare the form of different cities/regions as well as evaluate urban sprawl patterns (e.g. Triantakou et al., 2015; Prastacos et al., 2017; Lagarias & Sayas, 2018, 2019; Lagarias & Stratigea, 2021).

In this study, spatial metrics are calculated by use of multi-temporal data, provided by the Global Human Settlement Layer (GHSL) (Corbane et al., 2019) and the Corine Land Cover (CLC) inventory (<https://land.copernicus.eu/pan-european/corine-land-cover>); and are used to bring out the spatial component of coastalization as well as the dynamics of change and urban sprawl trajectories in coastal tourism destinations. This methodology is applied to four highly recognizable destinations that are marked as ‘hot spots’ of coastal urban sprawl in the Mediterranean, namely the: Costa Blanca/Murcia in Spain, Cote d’Azur in France, Emilia-Romagna (Adriatic Coast) in Italy and Crete Island in Greece. Coastalization and urban sprawl in these study regions are analyzed through the variation of spatial metrics for each single time spot and along different distance buffers from the coast, unveiling diversified coastalization typologies and urban sprawl patterns.

The *structure* of the paper is as follows: in “**Data and methods**” section the data and methodology are presented; in “**Results**” section the results obtained are analyzed and synthesized; in “**Identification of coastalization typologies**” section discussion of results is established and diversified coastalization typologies are articulated; and finally, in “**Conclusions**” section certain key conclusions are drawn.

Data and methods

Case study areas

In this work, four distinct, highly-rated tourism development hubs of the northern Mediterranean coast are analyzed and compared (Fig. 1). A common attribute of all four case study areas is their recognition as *coastalization* ‘hot spots’ due to mass tourism

development. According to Eurostat statistics¹ (2019 data), tourism pressures, quantified by nights spent in tourism accommodation divided by the total area in km², score among the highest values on a pan-European scale (1575–4000 nights spent per km²), in all case study areas. Mass tourism, coupled with high urban land expansion rates during the past few decades, render these areas typical examples of coastal urban sprawl development.

Costa Blanca/Murcia in Spain, as defined in the Urban Atlas database (western part of Murcia Province), consists of the Alicante Province (NUTS 3), with the addition of the Larger Urban Zones (LUZ) of Murcia and Cartagena in the south (and their in-between zone). Total area is 7927 km², coastline length reaches the 479 km, while population rises to 2.5 million (2011). The area is characterized by plain land with mountainous areas expanding in its northwestern part. It hosts 76 Natura 2000 sites (36% of total land). In Costa Blanca/Murcia population growth in the period 1991–2011 was pretty high, rising from 1.79 million in 1991 to 2.51 million in 2011, i.e. +40%. In the same period, population in major towns, i.e. Alicante, Murcia, Cartagena and Elche, grew by 20–30%, while population in Benidorm and Torrevieja coastal resort towns grew by 60% and 260% respectively.

Costa Blanca is a typical example of a coastal Mediterranean area, where the socio-ecological system suffers from excessive land transformation, population growth and development of activities (de Andrés et al., 2017), with quite visible signs of urban sprawl, suburbanization, extensive traffic and land exploitation (Membrado et al., 2016). Favorable climate conditions, mild temperatures and the abundance of beaches and pleasant landscapes fueled seasonal and residential tourism development in this area, which scores pretty high in terms of urban development indexes in the whole Spanish coast (de Andrés et al., 2017).

The central coastal part of Costa Blanca, including Benidorm and Alicante’s area of influence, has been identified as a “busy” domain for national tourism since the ‘70s (Sánchez-Rubio, 2008). Beyond this period, the southern coastal area, spanning from

¹ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Tourism_statistics_at_regional_level#Tourism_pressures.

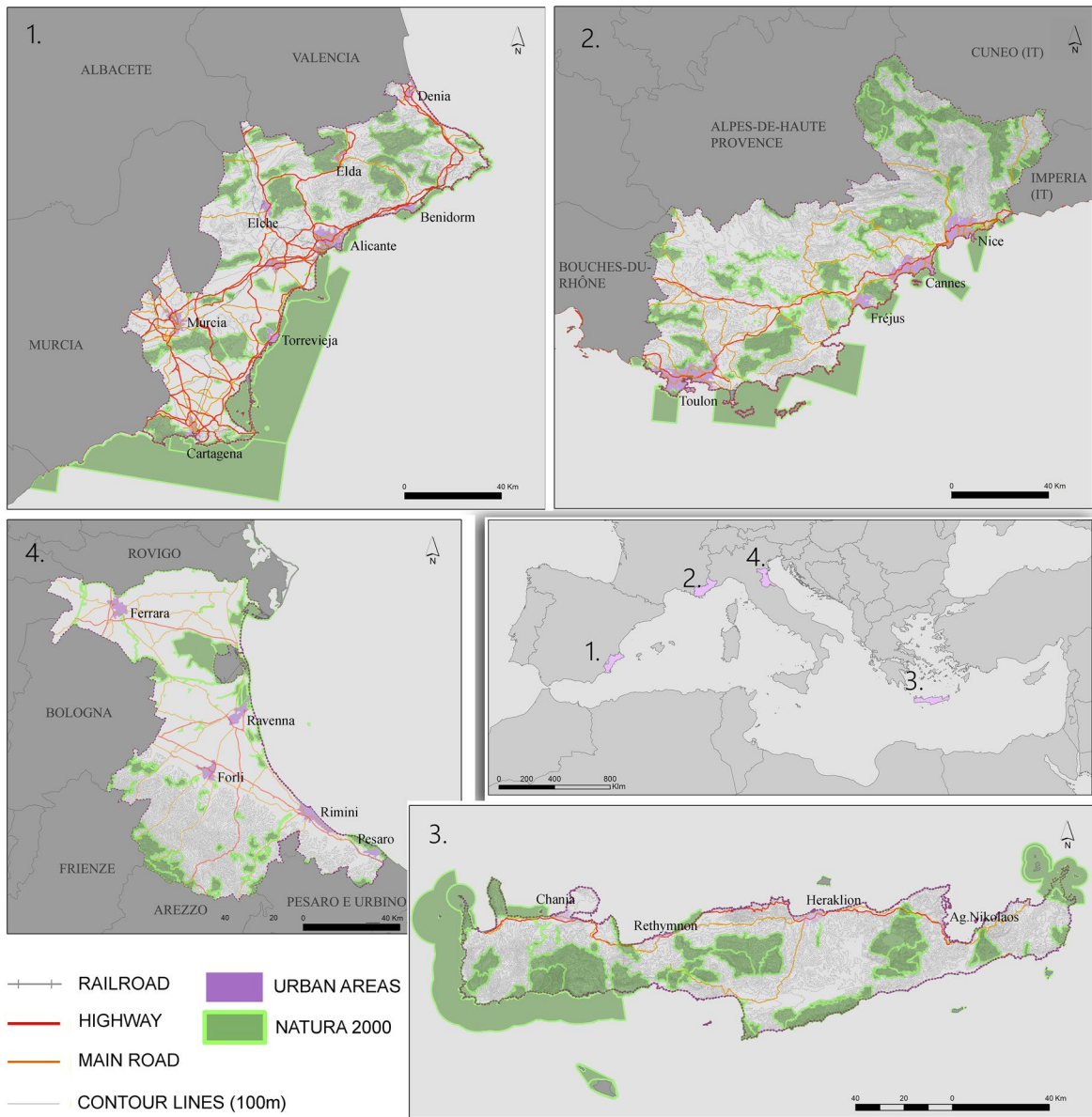


Fig. 1 Case study regions and their key spatial attributes (1 Costa Blanca/Murcia, 2 Cote d’Azur, 3 Crete, 4 Emilia-Romagna). Source: Own elaboration

Torrevieja to La Manga, is identified as the area with a great expansion of international tourism; while since the ‘80s, the northern part (Marina Alta region), including the coastal city of Denia, is mainly characterized by residential tourism and second-house development (Sánchez-Rubio, 2008). The inland zone is also partly urbanized, mainly around major cities like Elche and Murcia, located at a distance of about

30 km from the shore. Also, among the factors that guide overcrowding of Costa Blanca Region falls the mass migration of northern European retirees to Costa Blanca (Membrado et al., 2016). The influx of northern European immigrants, initiated in early 90’s and encouraged by public authorities and large construction companies, has led to urban sprawl in coastal areas. Moreover, in many cases the Spanish

model of tourism development is characterized by an out-of-scale transformation of the natural landscape. An exemplary case of such a transformation is La Manga, an area of unique topography that is located between the Mediterranean Sea and the salty lagoon of Mar Menor. Following the 1962 National Tourist Interest Act that steered and co-financed the development of large tourism resorts, large-scale tourism development projects were deployed, which have heavily accelerated urbanization processes in La Manga and have altered the state of the ecosystem, causing severe environmental impacts (Miralles i Garcia & García-Ayllón Veintimilla, 2013).

Cote d'Azur in France includes Var and Alpes-Maritimes Provinces (NUTS 3). Total area is 10,494 km², coastline length is 548 km, and population is 2.17 million (2019). The mountainous geomorphology restricts *Cote d'Azur* urban development towards the coastal zone and several inland plateau areas. In the eastern part, i.e. the Nice-Cannes area, the Alps are bounding urban development to a thin strip along the coastal zone. The area hosts 77 Natura 2000 sites (35% of total land). Today, this area, especially in the Alpes-Maritimes province, is considered as an almost fully urbanized coastal zone, including urban areas, historical settlements and tourist-oriented infrastructure. Major cities include Nice, Toulon, Frejus and Cannes. In the Var and Alpes Maritimes province, population grew by 21.5% in the time span 1990–2019, while over 80% of population resides in coastal areas.

Cote d'Azur is one of Europe's most urbanized coastal part, where agricultural and unprotected natural areas are threatened by urban expansion (Robert et al., 2019). It is host of major seaside resorts since the 19th century; while in the late 20th century it emerges as a renowned international tourist destination, with over 13 million visitors on a yearly basis. Tourism has become a major component of the regional economy, generating high revenues and a contribution of tourism to the economy that exceeds the 15%, in contrast to the 7.4% in France as a whole (<http://www.cotedazur-touriscope.com>). As a major tourism destination area since the early 20th century, hosting highly-reputed coastal cities like Nice and Cannes and the most important share of accommodation capacity, this area exhibits a high saturation level; while the coastal part presents recently a faint deconcentration trend. Indeed, according to Liziard,

(2013), the coastal part of the Alpes-Maritimes region has, since the '60s, a remarkable share of population concentration (89%) in the 0–10 km zone from coast that is reduced to about 83% in 2010, in favor of the inland zones.

Crete Island in Greece covers a total area of 8354 km². The length of the northern coastline is 601 km, while total population of the island is 0.62 million (2011). Crete is characterized by a mountainous morphology in its central and southern part, restraining development mostly along the northern axis, where land is relatively flat. It hosts 54 Natura 2000 sites (42% of total land of Crete Island). Major urban centers are also spread in the northern coast, including Heraklion, Chania, Rethymno and Agios Nikolaos, all four also being the capitals of related regional administrative entities as well as cities connected by the Cretan Northern Highway (VOAK). Population growth in Crete Island reached 16% in the time span 1991–2011. However, population gains are unevenly distributed, with coastal communities demonstrating certain dynamism as opposed to inland ones which, in most cases, are marked by population losses.

Crete is regarded as a highly-rated mass tourism destination since the '70s, with a notably mass tourism-dependent local economy. This, in turn, has fueled intense coastalization processes, mostly affecting the northern part of the island. On the contrary, the southern coast remains largely intact, while the central part exhibits strong population losses and an economic structure that is mostly featured by the prevalence of the agricultural sector (Lagarias & Stratigea, 2021). Crete is currently attracting yearly about 2 million foreign visitors (Matzarakis & Nastos, 2011). Tourism facilities include 1619 hotels with a sum of over 187,600 beds, while Airbnb platform has currently 18,000 registered rooms and houses/apartments, mostly concentrated along the northern coast and close to the major urban centers (Lagarias & Stratigea, 2021). Tourism-related employment also affects the constantly growing tertiary sector (reaching 65% of total employment in 2011), while direct employment in the tourism sector (hotels and restaurants) increased from 8% in 1991 to 15% in 2011.

Emilia-Romagna in Italy covers a total area of 7890 km². It includes the Ravenna, Ferrara, Forli-Cersena, and Rimini provinces (NUTS 3), while in its southwest boundary the coastal resort city of Pesaro

Table 1 General data of case study areas. *Source:* Own elaboration

Area	Total area (km ²)	Coastline length (km)	Population* (% increase)	Nr of natura 2000 sites (% of total land)	GHSL urban land expansion (1975–2014)
Costa Blanca/Murcia	7927	479	2.56 million (43%)	76 sites (36%)	91%
Cote d'Azur	10,494	548	2.17 million (21%)	77 sites (35%)	60%
Crete	8354	601	0.63 million (16%)	54 sites (42%)	23%
Emilia-Romagna	7890	298	1.55 million (8.1%)	68 sites (13%)	65%

*Population data are obtained from city population data, <https://www.citypopulation.de/>. Time period for Costa Blanca/Murcia is 1991–2019, for Cote d'Azur 1990–2019, for Crete 1991–2011 and for Emilia Romagna 1991–2022

Table 2 Spatial datasets available and their attributes. *Source:* Own elaboration

Database	Data source	Data type	Spatial resolution	Coverage	Temporal Span	Information provided
Corine land cover (CLC)	European environment agency	Raster, shapefile	Minimum mapping unit (MMU): 25 ha (LAEA Europe)	Europe-wide and Turkey	1990–2018	44 land cover categories
Global human settlement layer (GHSL)	Joint research centre	Raster	30 m (Pseudo mercator)	Global-wide	1975–2014	Built-up areas 0 = non built-up 1 = built-up

is located. The area's coastline length is 298 km and total population reaches the 1.55 million (2021). Emilia-Romagna is characterized by a smooth geomorphology, with flat agricultural land and the Apennine Mountains, covering the south-western part. Major transport infrastructure connects the area to Bologna and Milano on the northwest (European route E45) and Bari on the south (Adriatic highway A14). The area hosts 68 Natura 2000 sites (13% of total land), including the Parco Regionale del Delta del Po. Major urban areas are Pesaro, Ravenna, Ferrara, Forli and Rimini. Population growth depicts a rather moderate pattern, increasing by 8.1% in the time span 1991–2021. However, this seems to be much higher in coastal communities (e.g. population growth in Rimini reaches 18%) as opposed to the moderate population increase in inland cities.

The coastal zone of Emilia Romagna is part of the Italian Adriatic coastline that is considered as the longest urban stretch in southern Europe with a total coastline length of more than 1470 km (Romano & Zullo, 2014). Favored by flat formations, low and sandy beaches and a plane hinterland, facilitating infrastructure and residential settlements' deployment and manufacturing (Romano & Zullo, 2014),

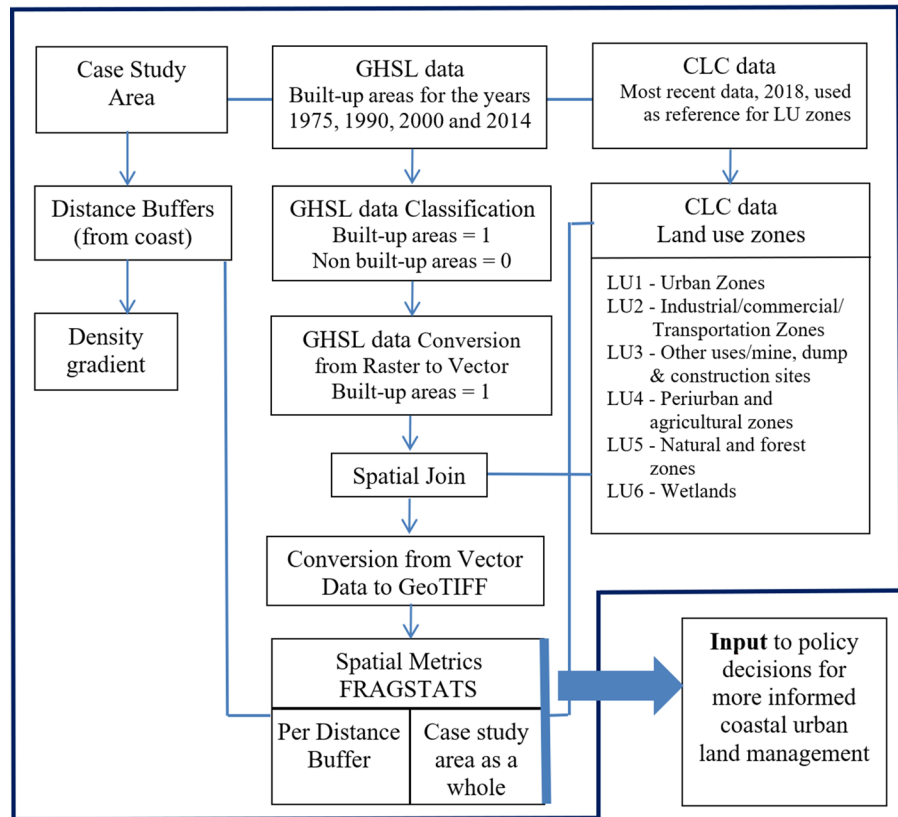
it has emerged as a tourism destination area. Emilia Romagna coast is one of the most famous coastal destinations in the northern Adriatic Sea, being steadily evolving as such in the past 50 years. Data shows that the percentage of coast that remains free from urban structures dropped from 96% in the '50s to 45% in 2014 (Romano & Zullo, 2014). Pressures posed on the local ecosystems and the agricultural land have been early enough identified in the 2000 Piano Territoriale Regionale (Regional Territorial Plan, PTR); while specific targets for land use planning are recently updated by Law no. 24/2017 (Cattivelli, 2020) (<https://territorio.regione.emilia-romagna.it/programmazione-territoriale/ptr-piano-territoriale-regionale>).

A summary of the key attributes of the study regions is presented in Table 1.

Spatial data and methodology

Assessment of coastal urban sprawl in this work is grounded in a combination of two *spatial datasets*, namely (Table 2):

Fig. 2 Steps of the methodological approach for spatial data processing



- (i) CLC data by the EEA (years 1990, 2018), mapping 44 land cover categories at a coarse resolution with Minimum Mapping Unit (MMU) set to 25 ha; and
- (ii) GHSLS data by the JRC (years 1975, 1990, 2000, 2014), namely a multitemporal raster dataset with global coverage, mapping built-up areas by use of a binary approach (built-up/non built-up) at a resolution of 30 m.

GHSLS data are used in this study to capture coastalization patterns in more detail. CLC data, although valuable in the exploration of land cover changes in agricultural and natural land, seem to be rather inappropriate for the analysis of coastal urban sprawl due to the CLC crude spatial resolution. Additionally, CLC data cannot really capture spatially-detailed processes of urban expansion due to principally two main reasons, namely: (i) a large portion of built-up areas are scattered within zones identified by CLC as agricultural and semi-natural or natural areas; and (ii) the 25 ha MMU impedes a sound comparison

between different versions of CLC, since an area of a given land use that is just under 25 ha would not be represented in the database, yet, it could appear at a later stage, when the 25 ha threshold is reached.

Spatial data processing is carried out by use of the methodological steps presented in Fig. 2.

At a *first step*, different GIS files for built-up areas in 1975, 1990, 2000 and 2014 are extracted from the GHSLS database. For each single time spot, a binary raster is created that incorporates cell values = 1 for built-up areas and values = 0 for non-built-up areas. GHSLS rasters are converted to vector, identifying a grid code = 1 for built-up areas.

Parallel to this process, distance buffers are used to construct the built-up density gradient and assess coastalization intensity in each single case study area. Buffers are used to estimate different sets of spatial metrics per distance from the coastline. Each case study is divided into buffer zones, covering areas of 1, 2, 4, 6, 8, 20 and > 20 km distance from the coastline. In Crete Island, where the coastalization process is mainly limited to the northern part, buffer distance

zones were estimated from the northern coast; while beyond the distance of 8 km, the remaining land is perceived as a single zone, covering the rest of the island to the southern part.

At a *second step*, built-up areas are categorized into different *land use (LU) zones*. The most recent version of *CLC data* (year 2018) is used as reference to define the subsequent zones: LU1 Urban zones, LU2 Industrial/Commercial/Transportation zones (corresponding to 121–124 land use categories/zones based on the CLC nomenclature), LU3 Mine, dump & construction sites (131–133 CLC zones), LU4 Periurban and agricultural zones (211–244 CLC zones, with the addition of 111–112, 141–142 zones that are not located within ‘urban areas’), LU5 Natural and forest zones (311–335 CLC zones), LU6 Wetlands (411–523 CLC zones).

Urban zones (LU1) are defined by using a variation of the Urban Morphological Zones’ methodology (Simón & Leal, 2011). Only core areas of large cities (included in the Urban Audit database) were considered; and contiguous Corine zones with CLC codes 111 (Continuous urban fabric), 112 (Discontinuous urban fabric), 121 (Industrial or commercial units), 123 (Port areas), 124 (Airports), 141 (Green urban areas) and 142 (Sport and leisure facilities) are merged. In case these zones include “pockets” of other classes, these are also considered as part of the urban zone. Based on the six land use zones, GHSL built-up areas are categorized into six corresponding Classes—e.g. Class 1: “Built-up areas within Urban Zones”, Class 2: “Built-up areas within Industrial/Commercial/Transportation zones”—by use of a spatial join process in the ArcGIS environment.

At a *final step*, vector data are converted to raster GeoTIFF files and are used as input to the FRAGSTATS software for estimating *spatial metrics* (both at a regional level and per distance buffer from the coast).

Spatial metrics

Spatial metrics’ estimations are based on the concept of patches as defined in the landscape ecology approach (Turner, 2005; Wu, 2006), i.e. discrete areas that appear to be homogenous with respect to certain attributes. In this study, spatial metrics are estimated at the level of *urban patches*. More specifically, four types of *spatial metrics* are assessed by use of

FRAGSTATS open software (McGarigal et al., 2012), corresponding to:

- (i) *Density* (Patch Density—PD, Edge Density ED),
- (ii) *Size/aggregation* (Mean Patch Size—MPS, Largest Patch Index—LPI),
- (iii) *Shape/geometry* (Shape Index—SHAPE, Gyrate—GYRATE), and
- (iv) *Dispersion* (Euclidean Nearest-Neighbor Distance—ENN, Connectivity Index—CONNECT) of built-up areas.

These are defined as follows:

- *Patch Density* (PD) the number of patches divided by the total area of the study zone.
- *Edge Density* (ED) total length (m) of edge in landscape, divided by total area of the study zone.
- *Mean Patch Size* (MPS) the mean area of patches of a class.
- *Largest Patch Index* (LPI) the area of the largest patch of a land use class, divided by the total area of the study zone.
- *Shape Index* (SHAPE) indicator that compares the actual perimeter of a patch to the minimum perimeter it could have in case of a simple geometrical shape.
- *Gyrate* (GYRATE) the mean distance (m) between each cell in the patch and the patch centroid. Gyrate is higher for large irregular/elongated patches.
- *Euclidean Nearest-Neighbor Distance* (ENN) the mean distance to the nearest neighboring patch of the same class, calculated as the shortest edge-to-edge distance.
- *Connectivity Index* (CONNECT) a measure of connection (joins) between patches of the same type, divided by the total number of possible connections among all patches of the corresponding patch type. Two patches are connected when their distance is smaller than a specified threshold distance (set as 200 m in this study).

A distinction between *landscape level and class level metrics* is also made. *The landscape level* refers to an overall estimation of spatial metrics, taking into account built-up areas as a whole; while the *class level* refers to different land use zones (as defined by

CLC data), and quantifies the attributes of a certain type of patches (e.g. Class 1: built-up areas within urban zones).

Estimations of spatial metrics are carried out for GHSL data sets in different *time spots*, namely 1975, 1990, 2000 and 2014.

Results

Land cover changes

CLC data are briefly demonstrated in this section to provide a crude representation of land cover changes in each study area in the period 1990–2018, while at a next step GHSL data are used to capture coastalization patterns in more detail, based on the methodological approach described in “[Data and methods](#)” section. The time frame of CLC data is different from the one of GHSL data (1975–2014), since the former were launched for the first time in 1990. However, since the scope of using CLC data in this study is to roughly present trends of land cover changes, this is not considered as a major problem. Density gradients and spatial metrics, presented in the next sections, follow strictly the GHSL time frame (1975–2014).

Costa Blanca/Murcia Agricultural land is mainly characterized by complex cultivation patterns, incorporating fruit trees and irrigated arable land, which in many cases are located very close to the coast. In 2018, agricultural land is shrunk to 50% of total land, displaying a negative change of -15.8% , compared to 1990. According to CLC data, artificial areas in the period 1990–2018 display an important increase from 4.8 to 10.9% ($+128.4\%$), mainly due to the expansion of discontinuous urban fabric and industrial/commercial areas. Sport and leisure facilities also increase from 308 to 3959 ha ($+1186\%$), a fact that is largely associated with the dynamic development of tourism- and leisure-related large scale infrastructure.

Cote d’Azur Agricultural land is scarce and fragmented, consisting mainly of vineyards (5% of total area), complex cultivation systems (4%), and trees and olives (0.7%). In the time span 1990–2018, the total agricultural land seems to be slightly decreasing from 15% to 13.3% of total area (change of -11.1%). In 2018, about 45% of the total area is covered by forests and another 24.5% by scrub and/

or herbaceous vegetation. Open spaces with little or no vegetation cover 6.4% of total area. Artificial areas increase from 69,328 ha (6.7% of total area) in 1990 to 102,873 ha (10% of total area in 2018, a change of $+48.4\%$), mainly due to discontinuous urban fabric that accounts for over 80% of artificial land in 2018.

Crete Agricultural land covers about 44% of total area in 2018, presenting a marginal increase of 2.6%, compared to 1990. Olive groves—a pillar of the primary sector economy—cover 25.9% of the island’s land. Forests cover only 3.5% in 2018. Artificial areas increase from 1.3% of total area in 1990 to 2.2% in 2018 (a change of $+65\%$). The share of artificial areas is much more critical in the northern part of Crete, i.e. the part most heavily affected by urbanization and coastalization trends. Discontinuous urban fabric, expansion of industrial/commercial areas and deployment of sport/leisure facilities are the most fast-growing land use categories in Crete Island.

Emilia-Romagna This is a predominately agricultural area, with agricultural land covering over 600,000 ha (77.5% of total land) in 1990, a share that is only marginally reduced in 2018 (-1.7%). Non-irrigated arable land and complex cultivation patterns are the main land cover types. The former is more frequently located in the vicinity of coastal zones, while the latter in the inland ones, at about 20–30 km from the coast and close to the inland cities of Faenza-Forli-Cesena. In 2018, forests cover about 10% of the total area, mainly in the mountainous south-western part, far from the coast; while small coniferous and mixed-forest areas are also detected around Ravenna, close to the coast. Inland/maritime wetlands cover 1.6% of total area, and their change is relatively small ($+5.7\%$). Artificial areas as a whole increased from 4.4% of total area in 1990 to 5.7% in 2018 (a change of $+28\%$), mainly due to discontinuous urban fabric and expansion of industrial/commercial areas.

Use of *GHSL data* unveils that important shares of built-up areas are constructed within zones identified by CLC as agricultural and natural areas, this fact confirming that dispersed low-density development, usually related to urban sprawl, cannot be detected by CLC data. For example, in *Costa Blanca/Murcia* more than 46,000 ha of built-up areas are tracked down within zones delineated by CLC as agricultural. Similarly, about 24,000 ha of built-up areas in *Emilia-Romagna* and 10,000 ha in *Crete* encroach within agricultural zones. In *Cote d’Azur*, 33,585 ha of

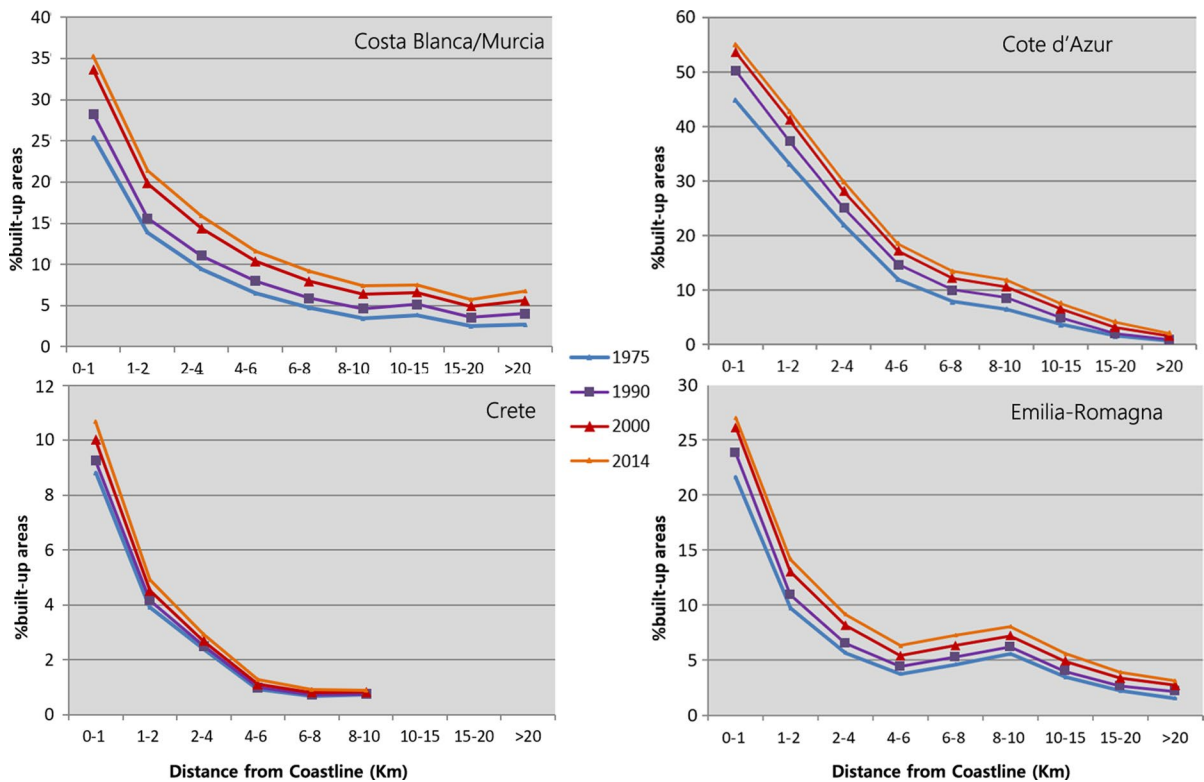


Fig. 3 Coastalization curves for the period 1975–2014 (% built-up areas) in different distances buffers from coastline. *Source:* Own elaboration

built-up areas are scattered within agricultural zones and another 13,756 ha in zones designated by CLC as forest/semi-natural areas.

Density gradients

GHSL data were overlaid by buffer zones, and statistics for the period 1975–2014 were calculated. The percentage of built-up areas, tracked down in each single zone, was used to construct density gradients, revealing coastalization evolution through time (Fig. 3).

In Cote d’Azur, the built-up density in the front coastal zone (up to 1 km from the coastline) is the highest among all case studies, reaching 55%, with this zone having already reached a saturation point. This percentage is lower in Costa Blanca/Murcia (35%), Emilia-Romagna (27%) and Crete (11%). In Costa Blanca/Murcia and Emilia-Romagna, urban development is further expanding towards the inland zones. In Cote d’Azur the level of urbanization drops

considerably along distance from the coast, yet, the curves remain relatively high in the hinterland (above 5%, beyond 6 km and up to the 15 km limit).

In Crete only the first three zones up to 4 km from coast are affected by urbanization processes.

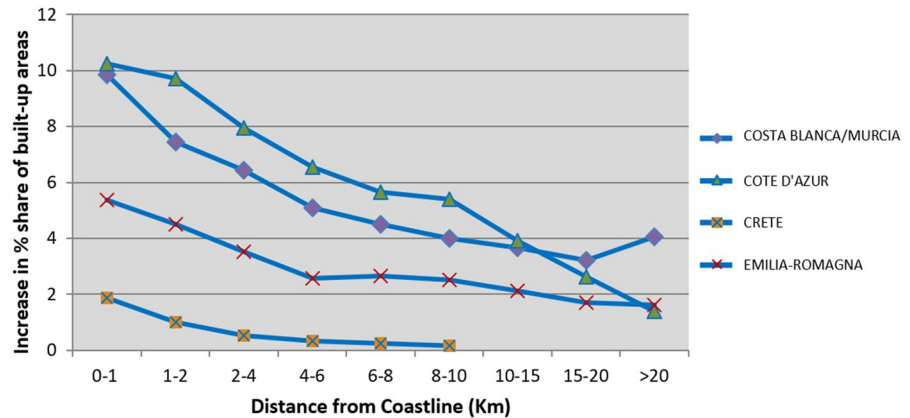
Density gradients can be approximated by a negative exponential curve of the type:

$$D(r) = a \cdot e^{-b \cdot r} \tag{1}$$

where D is the built-up density, r is the distance from coast, a is a constant value related to built-up density at zero distance from coast and b is a parameter, defining the slope of the exponential curve. Value of b can be estimated through linear regression, following a logarithmic transformation of Formula 1.

Higher b values demonstrate a sharper decline in density gradient and, therefore, a more intense coastalization pattern, i.e. built-up areas that are more concentrated in the “immediate” coastal zones. Linear regression results are statistically significant and

Fig. 4 Increase in % of the share of built-up areas per distance zone in the time span 1975–2014. *Source:* Own elaboration



show that in 2014, the highest b values are reported in Crete (0.91, $R=0.99$), followed by Cote d'Azur (0.81, $R=0.94$), Emilia-Romagna (0.50, $R=0.97$) and Costa Blanca/Murcia (0.47, $R=0.98$). Moreover, by comparing b values through time, it is observed that in Costa Blanca/Murcia and Cote d'Azur, b is rapidly decreasing in the period 1975–2014 (24% and 23% respectively), this fact being related to a flattening of the coastalization density gradient. This appears to be an expected and normal process, as coastal concentration displays an intense pattern for a long time, therefore, at a next stage of development urban expansion is more rapid in the hinterland. In Emilia-Romagna the flattening of the curve through time is moderate (b decreases by 15%); while in Crete b appears almost stable through time.

Comparative analysis of urban density changes (as demonstrated by the increase in % of the share of built-up areas per distance zone in the time span 1975–2014) is shown in Fig. 4. In all case study examples, built-up areas have expanded, presenting a noticeable growth of their shares (%) (Fig. 4). For instance, in the zone 0–1 km, the percentage of the total land covered by built-up areas increases by 10% in Costa Blanca/Murcia, 10.2% in Cote d'Azur, 5.4% in Emilia-Romagna and 1.9% in Crete. In the cases of Costa Blanca/Murcia and Cote d'Azur, new constructions seem to be important at least up to 6 km distance from coast, with the increase in % share of built-up areas in this zone being higher than 5%. Additionally, for these two case studies, construction interest continues to be present in zones with distance greater than 6 km from coast too, gaining higher values when compared to the rest two case study examples. In

Emilia-Romagna, the increase in % share of built-up areas beyond the distance of 4 km is relatively steady and is about 2%.

Spatial metrics results

Spatial metrics (landscape level) in the period 1975–2014 are reported in Table 3 and displayed in the corresponding graph of Fig. 5. Since urban sprawl mainly occurs in periurban and agricultural zones, separate sets of metrics for Class 4 patches (built-up patches located in LU4 zones) are also reported in Table 4. Results for all Class metrics (Classes 1–6) are reported in the “Appendix”. Interpretation of outcomes demonstrates that PD increases by 51.3% in Costa Blanca/Murcia, followed by 46.4% in Emilia-Romagna and then by 23.3% and 20.2% in Crete and Cote d'Azur respectively. However, the overall PD increase at the landscape level is mainly attributed to Classes 3–6; and especially to Class 4 (periurban and agricultural zones), with PD 4 displaying an increase over 60% in certain cases, e.g. Costa Blanca/Murcia and Emilia-Romagna. On the contrary, PD 1 and PD 2 decrease in all case study areas (apart from PD 2 in Crete), accompanied by an important increase in MPS 1 and MPS 2.

MPS in Cote d'Azur (4.68) is considerably higher than in Costa Blanca/Murcia (1.97), Emilia Romagna (2.19) and Crete (1.38); and increases rapidly through time (33%), as large clusters tend to be formed, and continuous urban fabric is being developed. This is justified by the high LPI value in Cote d'Azur (1.53). As new development takes place, separate clusters tend to merge together in certain areas, forming thus

Table 3 Spatial metrics and temporal changes in the period 1975–2014 (landscape and class 4 levels). *Source:* own elaboration

Landscape	PD	ED	LPI	MPS	GYRATE	SHAPE	ENN	CONNECT
Costa Blanca/Murcia	4.81	30.8	0.75	1.97	33.3	0.61	146.3	0.010
Change (%)	51.3	58.3	38.1	26.6	4.9	0.6	−7.2	−45.7
Cote d'Azur	1.71	18.0	1.53	4.68	32.6	0.59	190.7	0.022
Change (%)	20.2	41.3	20.2	33.0	17.6	3.4	1.7	−16.6
CRETE	1.37	8.9	0.31	1.38	31.8	0.64	194.4	0.028
Change (%)	23.3	21.2	4.9	−0.1	1.6	0.2	−6.2	−21.9
Emilia-Romagna	2.22	15.7	0.30	2.19	31.8	0.63	165.6	0.011
Change (%)	46.4	50.4	106.8	13.5	6.0	0.7	−11.1	−42.7
Class 4	PD 4	ED 4	LPI 4	MPS 4	GYRATE 4	SHAPE 4	ENN 4	CONNECT 4
Costa Blanca/Murcia	3.89	21.85	0.2	1.47	32.7	1.24	124	0.009
Change (%)	63.2	82.7	379.1	33.7	7.9	1.6	−11.1	−38.4
Cote d'Azur	1.17	9.93	0.22	2.78	31.8	1.22	139	0.019
Change (%)	11.0	46.3	315.1	62.7	22.8	4.6	−4.0	−11.6
CRETE	1.23	6.45	0.02	1.02	30.3	1.22	146	0.025
Change (%)	24.3	27.4	28.4	3.7	1.6	0.3	−6.0	−21.0
Emilia-Romagna	2.03	11.35	0.15	1.47	30.7	1.22	153	0.010
Change (%)	60.6	71.5	102.6	12.9	6.8	1.2	−16.5	−33.5

larger clusters. This results in an increase of MPS and LPI through time.

In Crete, although PD increases, MPS remains stable. The increase of GYRATE in all case study regions is attributed to the fact that patterns become more complex in geometrical terms. High GYRATE values are also related to large elongated patches of built-up areas that are usually formed along transportation axes and/or the coast. SHAPE presents fluctuation through time, a fact related to the dynamic process that transforms the geometry of the spatial pattern. CONNECT decreases in all case study regions in the period 1975–2014. However, this decrease is lower in the case of Cote d'Azur, where connectivity decreases in the period 1975–2000, followed by a marginal increase in the period 2000–2014. Connectivity decrease is mainly attributed to Classes 3, 4, 5 and 6 patches, since results show that CONNECT 1 and CONNECT 2 increase in all case study areas. Similarly, ENN 1 and ENN 2 increase in all case study areas with an exception of ENN 2 in Crete, where industrial/commercial areas become more dispersed through time (ENN 2 change −17%). On the contrary, ENN 3, ENN 4 and ENN 5 decrease in all case study areas, with the only exception being ENN 5 in Emilia-Romagna (change +39.5%). ENN decreased

in Costa Blanca/Murcia (−7.2%), Emilia-Romagna (−11.1%) and Crete (−6.2%), while it increases in Cote d'Azur (+1.7%). Therefore, in all case study areas, apart from Cote d'Azur, built-up compartments, although they come closer, they still remain less connected at the local level (threshold of 200 m).

Spatial metrics per distance from coast are estimated for the year 2014 (Fig. 6). Key results, regarding the variation of spatial metrics per distance zone, are as follows:

PD–ED In Costa Blanca/Murcia PD is increasing with distance from coast, especially in the buffer zones up to 10 km. Beyond this distance PD decreases, as built-up development is more compact around inland cities. Similarly, in Emilia-Romagna, PD profile displays high values in the distance zones 2–10 km from coast, mainly attributed to the 'patchy' development in inland agricultural zones, not directly related to coastalization. In Cote d'Azur, PD variation is smaller across distance from coastal zones; while in Crete PD presents a local peak at the 4–6 km distance from coast. ED in all case study regions presents an almost linear decrease with distance from coast.

MPS–LPI MPS profiles are almost identical in Emilia Romagna and Costa Blanca/Murcia. These are rapidly decreasing beyond the 0–1 km zone; and

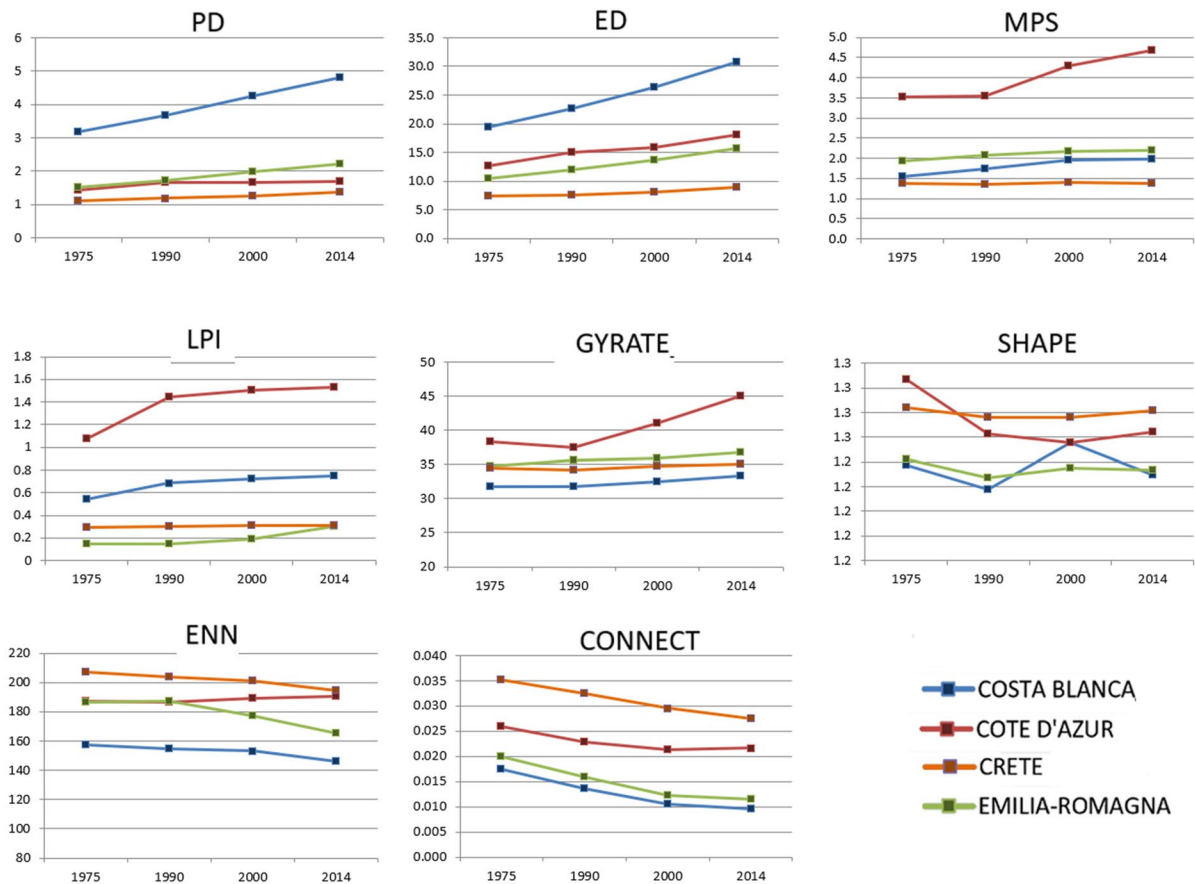


Fig. 5 Graphs of selected spatial metrics in 1975, 1990, 2000 and 2014. *Source:* Own elaboration

only marginally increasing in Emilia-Romagna inland areas that fall into a distance from coast of 6–15 km. In Cote d'Azur, MPS is very high; however, this drops considerably with distance from coast. LPI scores are very high in the 0–1 km zone in Cote d'Azur (value = 70, associated with the large coastal agglomeration in Nice), then drops considerably. In Costa Blanca, LPI starts from 2.6 in the 0–1 km distance from coast, drops gradually to 0.4 in the 8–10 km zone, and then rises to 2.5, an increase that is associated with the large inland city of Elche.

SHAPE–GYRATE In Costa Blanca/Murcia, SHAPE displays a decrease with distance from coast. In Emilia-Romagna, SHAPE decreases from 1.37 in the 0–1 km zone to 1.22 in the 4–6 km zone, then increases. Similar fluctuations with local peaks in the inland zones are also presented in Cote d'Azur; while in Crete SHAPE is maximized at a distance 2–4 km from coast. GYRATE presents a slight

decrease with distance from coast in Cote d'Azur and Costa Blanca/Murcia; while in Emilia-Romagna GYRATE increases locally in the inland zone. In Crete, GYRATE is maximized at the distance 2–4 km from coast, in a similar way as SHAPE. This could be attributed to the effect of the VOAK highway that runs along the northern coast of the island (in most cases at about this distance zone), advocating a complex and fragmented developmental pattern.

ENN–CONNECT Connectivity of built-up areas generally decreases with distance from coast, as expressed by low CONNECT values. An exception is observed in Cote d'Azur, where CONNECT slightly increases in the 4–6, 6–8 and 8–10 km distance from coastal zones; while in Crete a local peak is observed in the 6–8 km zone. ENN displays low values in the immediate coastal zone (0–1 km) in all case study areas; and generally increases with distance from coast. In Costa Blanca/Murcia, ENN increases

Table 4 Coastalization typologies and urban sprawl assessment, based on spatial metrics

	Density gradient	Patch density	Size/aggregation	Shape/geometry	Dispersion
Coastal urban sprawl	Steep slope	High levels of patch/edge density	Low levels of patch aggregation, fragmented	Complex/irregular and elongated patches	High levels of dispersion with low patch connectivity
Costa Blanca/Murcia	Medium slope/Rapidly flattening db < 20%	Very high and rapidly increasing dPD, dED > 50%	High and increasing dMPS > 25% dLPI > 35%	Relatively high and steadily increasing dSHAPE ≥ 1% dGYRATE > 1%	Low with decreasing connectivity dENN < 5% dCONNECT < 45%
Cote d'Azur	Steep slope/rapidly flattening db < 20%	Relatively high and steadily increasing dPD > 20% dED > 40%	Very high and rapidly increasing dMPS > 30% dLPI > 40%	Relatively low and increasing dSHAPE > 1% dGYRATE > 15%	Low, with slightly decreasing connectivity dENN > 1% dCONNECT < 15%
CRETE	Very steep slope/Stable db < 1%	Low and steadily increasing dPD, dED > 20%	Low and stable dMPS < 0% dLPI > 1%	Relatively low and stable dSHAPE > 0% dGYRATE > 0%	High and increasing dENN < 5% dCONNECT < 20%
Emilia-romagna	Medium slope/flattening db < 15%	Relatively high and increasing dPD, dED > 40%	MPS high, LPI Low/Increasing dMPS > 10% dLPI > 100%	Relatively low and steadily increasing dSHAPE > 0% dGYRATE > 5%	High with decreasing connectivity dENN < 10% dCONNECT < 40%

gradually with distance from coast; while in Crete ENN presents important fluctuations and is maximized in the 6–8 km zone. In both Emilia-Romagna and Cote d'Azur two local peaks are observed with respect to ENN, in the 1–2 km and the 8–10 km zone.

Identification of coastalization typologies

Quantitative assessments of spatial metrics in the specific case studies indicate that urban expansion in the northern Mediterranean coastal zones displays complex and spatially-differentiated patterns with regard to urban sprawl.

More specifically, urban sprawl seems to mainly be related to high levels of patch and edge density (high PD, ED); low levels of patch aggregation (low MPS, LPI), revealing a fragmented type of urban development; complex/irregular patch shapes (high SHAPE, GYRATE); and high levels of patch dispersion with low connectivity (high ENN, low CONNECT) (Lagarias & Sayas, 2019; Lagarias & Stratigea, 2021). Estimation of spatial metrics at different time spots unveils *changes over time*. Indeed, an increase in PD and ED values, is demarcating the *intensification of urban sprawl*. Additionally, urban sprawl is

usually associated with increasing geometrical complexity of urban patterns (as measured by SHAPE and GYRATE); while in case that CONNECT decreases and ENN increases, urban areas become more dispersed and less connected at the local level.

Key results obtained by the four case study regions demonstrate diversified *coastalization typologies* and a varying degree of *urban sprawl*. An assessment of spatial metric values, coupled with information regarding the slope of density gradient/speed of urban expansion, is codified/compared in Table 4, while characteristic coastal urban sprawl patterns in the case study areas are mapped in Fig. 7.

More specifically, *Costa Blanca/Murcia* presents the highest rate of urban land growth (up to 90% in about 40 years, as GHSL data displays); while spatial metric values indicate an extensive urban sprawl and fragmentation. Coastalization density gradient is flattening through time at a considerable rate (25%), affecting an area that extends up to 15 km from the coast. Built-up patterns are characterized by high and rapidly increasing patch/edge density, high and increasing aggregation, relatively high complexity/irregularity of patch shapes, and high levels of dispersion with decreasing connectivity. Therefore, *Costa Blanca/Murcia* typology is captured as

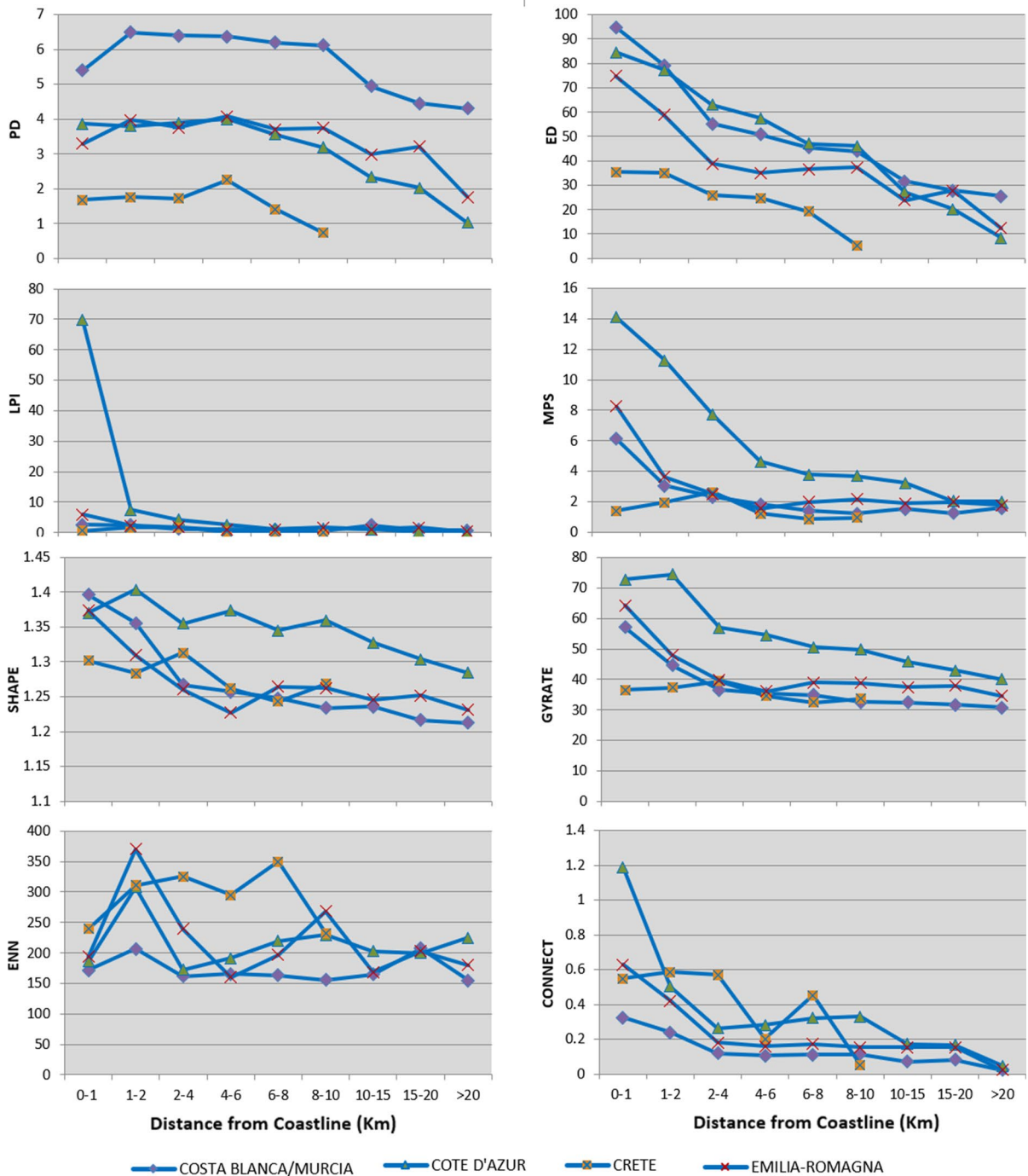


Fig. 6 Spatial metrics per distance zone from coast. *Source:* Own elaboration

an *accelerating sprawl*, with increasing dispersion, expanding towards the inland. This is also associated with a very intense mass tourism development model

that leads to extended construction projects along the coast, even within ecologically-sensitive areas.

A relatively similar situation can be inferred for *Emilia-Romagna*, where spatial patterns display

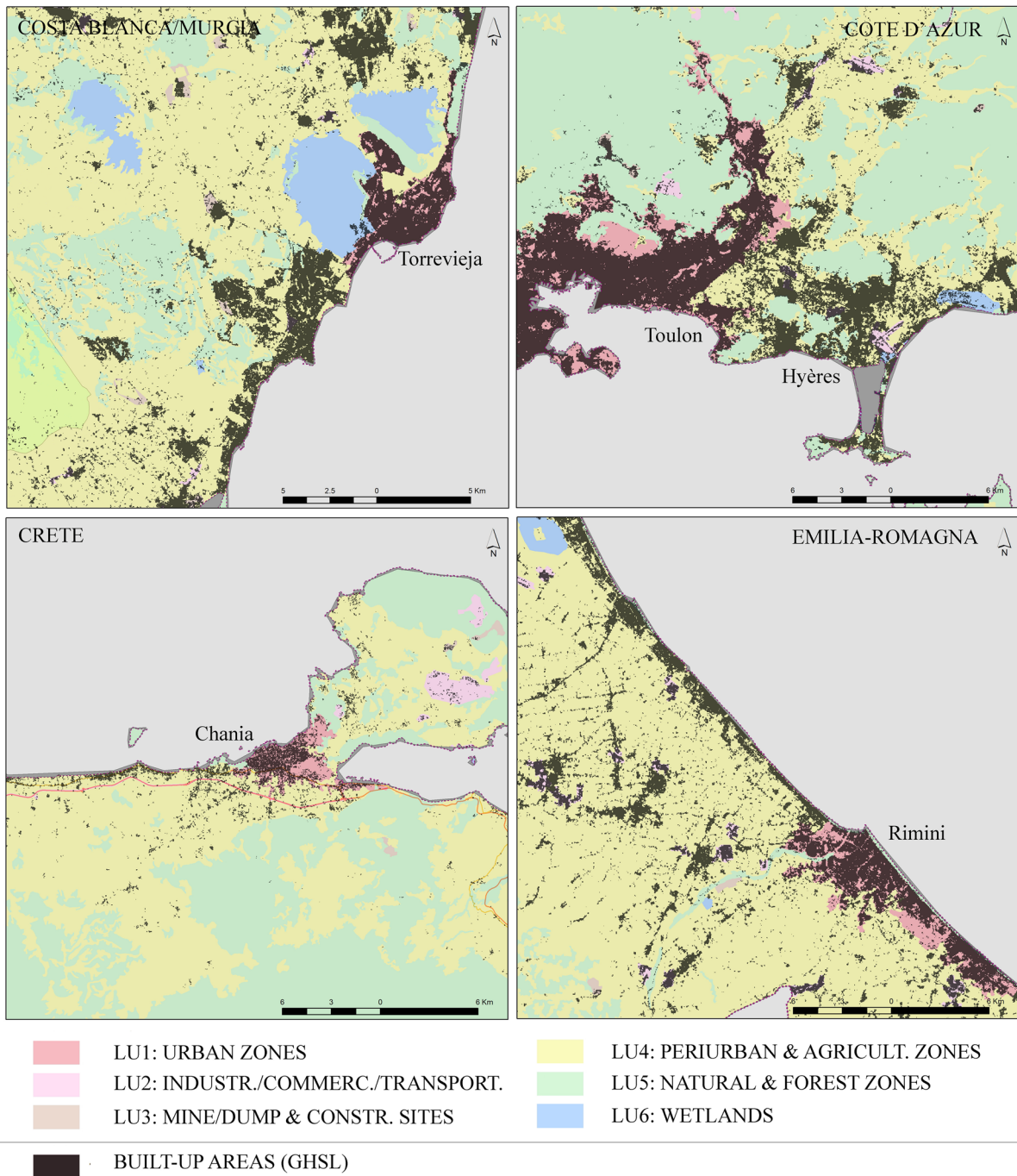


Fig. 7 Characteristic coastal urban sprawl patterns in the case study areas. *Source:* Own elaboration

several common characteristics with Costa Blanca/Murcia. Indeed, a remarkable similarity in spatial metric values is revealed between the two case studies, especially in terms of MPS, SHAPE and

CONNECT. Nonetheless, certain divergence is observed in values of: LPI, which rates lower due to the lack of a dominant urban cluster; and PD and ED, which although rapidly increasing, they are still

relatively low in comparison to respective values in Costa Blanca/Murcia. Based on this divergence, it seems that urban sprawling speed in Emilia-Romagna rates lower than in Costa Blanca/Murcia. Emilia-Romagna region, nevertheless, displays certain dynamic coastalization trends. Tourism-related development is mostly affecting a zone up to 2 km from coast; and is associated with a network of relatively compact inland urban centers, located along the E45 highway that connects the Adriatic coast to Bologna and Milano region; and scattered development within agricultural inland zones. Coastalization density gradient is flattening through time, but with a moderate rate (15%). Therefore, Emilia-Romagna typology is featured as a *dynamic sprawl with increasing dispersion*.

In *Cote d'Azur*, built-up patterns are characterized by relatively high and steadily increasing patch/edge density, very high and rapidly increasing aggregation, relatively low complexity/irregularity of patch shapes and low levels of dispersion. Overall, a more compact built-up pattern is observed, especially in the oversaturated, close to coast, zones in the Alpes-Maritimes province. This could be partly attributed to the rough geomorphology of the Alpes, covering the eastern part of the region. Around the city of Toulon, however, a slightly different pattern is observed with low density, yet continuous development. Urban sprawl expands rapidly towards the hinterland, along the transportation axis and the plateau areas of Aix-en-Provence, where geomorphology is smooth. This process is combined with a slight population deconcentration towards the inland settlements (Liziard, 2013). *Cote d'Azur* typology is therefore delineated as a *dynamic, compact and spreading towards the inland*.

In contrast to the aforementioned examples, urban expansion in *Crete* is rather moderate and coastalization seems to be “swallow”, disposing a very steep density gradient, with built-up developments concentrating around medium-sized, compactly built coastal cities, like Heraklion, Rethymno and Chania; and along a thin zone up to 2 km from the northern coast. This can be attributed to the: effect of the VOAK highway that runs along the northern coast of the island, connecting all major infrastructures; and intense mass-tourism development taking place since the '80s that renders the coastal zone a highly attractive place for investments. Built-up patterns are

characterized by relatively low and steadily increasing patch/edge density, low and stable aggregation, relatively low and stable complexity/irregularity of patch shapes, and high dispersion with rapidly decreasing connectivity. *Crete* typology in this respect is classified as *transitional, spreading along the coast*.

Conclusions

The coastal part of the Mediterranean region is currently an exemplary case of coastalization and urban sprawl tensions. In fact, intense urbanization and urban sprawl are heavily transforming the Mediterranean coastal landscape; while this is further burdened by *mass tourism development*, rendering vulnerable natural and man-made ecosystems more prone to disastrous situations. These processes demarcate an unsustainable developmental trajectory and render obvious the urgency for featuring more sustainable and resilient pathways. Reversing current unsustainable paths in coastal areas and dealing with emerging risks in a proactive way implies the need for assessing and steadily monitoring changes, and using this knowledge for feeding place-specific policy decisions.

The proposed methodological approach aims at fulfilling this need, by focusing on the analysis of spatiotemporal dynamics of coastal urban sprawl patterns, based on spatial metrics. Grounded in GIS technology and the combined use of high resolution multi-temporal data, provided by the GHSL database and the CLC data, it can be a useful ground for properly informing planning and policy endeavors that address the sustainable management of coastal zones. *Data, tools and technologies*, embedded in this approach, can be used in order for past and present developments and trends of urban sprawl and coastalization in coastal regions to be captured; and relative regulating or remediating land use policy decisions to be featured, e.g. delineation of land uses, building rules and restrictions, restraining of further urban expansion in the neighbourhood of coastal areas, to name but a few. They also constitute useful means for steadily *monitoring the performance* of such policies against urban sprawl; and identify potential policy gaps for further reaction/remediation.

Implementation of the proposed methodological approach is carried out in coastal areas of Spain, Italy, Greece and France, i.e. the flagship of tourism

destination areas in the Mediterranean, while it could be easily replicable to other coastal regions for capturing/quantifying aspects of coastal urban sprawl. Use of the proposed methodology leads to the identification of diversified typologies and underlines the need for comparative analyses of the coastalization phenomenon. Moreover, this work may be the ground for the making of spatial planning policies in coastal regions where seizing urban sprawl is critical, in order to properly handle potential negative impacts of intense pressures on their coastal land and maritime systems.

A major conclusion is that such innovative methodologies that are capable of identifying coastalization patterns and their dynamics can provide the ground for comparative analyses and establish distinct urban sprawl typologies as well as shared reactions to common risks. The latter can support more coherent and integrated strategies in the Mediterranean as a whole; while their downscaling at the local/regional level can address vulnerabilities of specific coastal areas' typologies. This knowledge can be used for building-up dedicated, place-specific and spatial data-driven coastal urban development and resilience strategies in the highly vulnerable Mediterranean coastal environment.

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Declarations

Conflict of interest We assure that there are no conflicts of interest.

Human and animal rights This research does not involve Human Participants and/or Animals and all sources of funding have been precisely mentioned.

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Appendix

Spatial metrics (class level), and temporal changes in the period 1975–2014 | *Source* own elaboration.

Class 1	PD 1	ED 1	LPI 1	MPS 1	GYRATE 1	SHAPE 1	ENN 1	CONNECT 1
Costa Blanca/ Murcia	0.07	3.59	0.745	34.9	78	1.52	85	0.53
Change (%)	−63.3	5.4	38.1	342.7	71.9	12.6	4.4	123.1
Cote d'Azur	0.07	3.29	1.533	45.7	71	1.36	103	0.36
Change (%)	−38.6	−6.5	43.1	98.5	27.0	1.3	4.7	57.3
CRETE	0.05	1.15	0.310	11.8	60	1.54	121	0.96
Change (%)	−9.9	3.9	4.9	22.0	14.9	4.6	54.6	13.0
Emilia-Romagna	0.06	2.35	0.303	25.3	92	1.64	87	0.63
Change (%)	−49.1	9.5	106.8	175.5	62.3	14.2	1.0	85.7

Class 2	PD 2	ED 2	LPI 2	MPS 2	GYRATE 2	SHAPE 2	ENN 2	CONNECT 2
Costa Blanca/Murcia	0.16	1.94	0.130	4.62	56	1.41	161	0.14
Change (%)	−35.8	−0.4	44.4	130.4	32.8	5.5	31.7	7.6
Cote d'Azur	0.04	0.52	0.041	5.96	67	1.50	236	0.52
Change (%)	−27.1	−3.3	52.7	68.8	23.0	6.0	49.0	34.3
CRETE	0.05	0.26	0.004	0.97	35	1.27	177	0.59
Change (%)	18.2	26.6	0.0	10.0	5.4	1.5	−17.0	−1.8
Emilia-Romagna	0.06	0.91	0.021	6.50	73	1.52	191	0.37
Change (%)	−30.2	25.5	35.4	146.0	55.2	12.6	6.2	13.5
Class 3	PD 3	ED 3	LPI 3	MPS 3	GYRATE 3	SHAPE 3	ENN 3	CONNECT3
Costa Blanca/Murcia	0.12	0.72	0.013	1.37	38	1.31	155	0.27
Change (%)	30.7	51.7	2.2	18.6	12.9	4.7	−20.4	−18.2
Cote d'Azur	0.02	0.09	0.002	1.14	38	1.28	369	1.22
Change (%)	64.4	70.7	14.3	−1.1	1.5	1.8	−26.0	−18.0
CRETE	0.01	0.04	0.002	1.21	39	1.35	1125	2.72
Change (%)	41.5	47.5	12.5	9.0	−0.4	−0.3	−61.5	−55.4
Emilia-Romagna	0.01	0.07	0.001	1.41	41	1.29	359	1.71
Change (%)	66.1	113.6	20.0	41.2	19.2	3.7	−55.1	−7.4
Class 4	PD 4	ED 4	LPI 4	MPS 4	GYRATE 4	SHAPE 4	ENN 4	CONNECT 4
Costa Blanca/Murcia	3.89	21.85	0.257	1.47	32.7	1.24	124	0.009
Change (%)	63.2	82.7	379.1	33.7	7.9	1.6	−11.1	−38.4
Cote d'Azur	1.17	9.93	0.224	2.78	44.6	1.32	139	0.019
Change (%)	11.0	46.3	315.1	62.7	22.8	4.6	−4.0	−11.6
CRETE	1.23	6.45	0.023	1.02	34.4	1.28	146	0.025
Change (%)	24.3	27.4	28.4	3.7	1.6	0.3	−6.0	−21.0
Emilia-Romagna	2.03	11.35	0.146	1.47	34.4	1.22	153	0.010
Change (%)	60.6	71.5	102.6	12.9	6.8	1.2	−16.8	−33.5
Class 5	PD 5	ED 5	LPI 5	MPS 5	GYRATE 5	SHAPE 5	ENN 5	CONNECT 5
Costa Blanca/Murcia	0.55	1.87	0.052	0.71	25	1.14	293	0.03
Change (%)	121.2	114.8	16.7	−10.1	0.0	0.2	−20.2	−52.3
Cote d'Azur	0.40	3.49	0.133	3.35	41	1.25	332	0.03
Change (%)	120.3	199.4	27.4	47.8	16.1	4.7	−25.1	−54.2
CRETE	0.04	0.13	0.002	0.55	27	1.17	1240	0.22
Change (%)	63.8	71.1	166.7	15.3	1.4	−1.1	−18.8	−45.0
Emilia-Romagna	0.06	0.27	0.009	0.97	33	1.21	443	0.29
Change (%)	18.0	33.6	14.3	24.7	5.8	0.6	39.5	−15.5

Class 6	PD 6	ED 6	LPI 6	MPS 6	GYRATE 6	SHAPE 6	ENN 6	CONNECT 6
Costa Blanca/Murcia	0.03	0.09	0.006	0.58	25	1.14	463	0.71
Change (%)	80.5	62.6	40.0	−20.9	−3.9	−0.3	−53.1	−22.3
Cote d'Azur	0.01	0.06	0.001	0.79	32	1.21	645	1.19
Change (%)	25.9	−1.2	−62.5	−36.3	−13.2	−5.2	−25.0	−34.8
CRETE	0.00	0.00	0.000	0.22	18	1.00	18,799	4.76
Change (%)	−22.2	−42.9	−100.0	−53.5	−22.4	−6.6	69.1	−14.3
Emilia-Romagna	0.01	0.04	0.001	0.52	26	1.16	895	0.80
Change (%)	96.0	152.3	0.0	38.0	15.0	5.5	39.2	−69.4

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