Indicators Engineering for Land Use Changes Analysis. A Study on the Mediterranean Coastal Strip

Francesco Zullo, Cristina Montaldi(✉), Lorena Fiorini, Alessandro Marucci, and Bernardino Romano

University of L'Aquila, 67100 L'Aquila, Italy
{francesco.zullo,lorena.fiorini,alessandro.marucci,
bernardino.romano}@univaq.it,
cristina.montaldi@graduate.univaq.it

Abstract. Since historical times, coastal areas have been the most extensively transformed territories worldwide. Even today they are subject to strong transformational pressure due to various reasons, mainly tied to climate, greater accessibility to infrastructure networks and services, and mass tourism, which is one of the main sources of income and anthropogenic impact. Landscapes and ecosystems are now largely impacted, especially in the Mediterranean area, due to the better climatic conditions. In recent years, the significant transformative drive that marked the last decades of the past century has decreased in intensity as a result of the growing awareness of environmental issues. The aim of our paper is to analyze land use transformations between 1990 and 2018 in the 500-m shoreline strip, paying special attention to settlement development. This helps gear possible actions/strategies aimed at improving current environmental conditions within the framework of territorial policies to achieve sustainability.

Keywords: Coastal urbanization · Mediterranean Coast · Urbanization impact

1 Introduction

Dualism is the noun that describes the condition of almost all of the world's coastal areas. Although they are an important source of resources, economies and ecosystem services, they are subject to increasing anthropogenic pressure that undermines their integrity and conservation [1–4]. This is even more evident in closed or semi-closed seas, such as the Mediterranean Sea, where an increase in the intensity and frequency of man-made changes, together with ongoing climate change, have led over time to coastal degradation and loss of environmental quality [5–11]. The distinctive morphological and geological conformation of the Mediterranean basin, together with its particular biogeographical characteristics, make it unique in the world [12–14]. This area has always been an important crossroads for the civilizations that followed one another in different historical eras [15], when the sea was the main communication route to establish

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trade relations between peoples, but also the scene of battles for political and military dominance. In the age of geographical discoveries, with the opening of new trade routes across oceans, the center of gravity of international relations and trade began to gradually shift beyond the Strait of Gibraltar, resulting in a decrease in internal trade. The opening of the Suez Canal in 1869 led to a further decline in trade traffic importance with major consequences for local economies [16]. From this period onwards, mass tourism became one of the main economic activities in these places [17–19]. In recent decades, urban transformation related to activities of this type is starting to encroach more and more intensely on various coastal areas along the over 16,600 km coastline [20–22]. This system affects 6 of the 27 States of the European Community which, together with the coastal areas of Albania, Turkey and Montenegro, have been investigated in this study. All the various islands in the Mediterranean basin have been excluded. This paper focuses on a strip of 500 m from the shoreline, dividing it among the different administrative units considered at the third level (NUTS - Nomenclature of territorial units for statistics), excluding all the various islands. The total expanse amounts to about 8,000 km^2, divided into 123 administrative units having an average size of 65 km^2 (Median: 50 km^2 – IQR: 61 km^2). No information is available on demographic density in this strip. The analysis of global population distribution maps having a 1 km/pixel resolution (https://landscan.ornl.gov/), available from 2000 to 2018, shows a population increase of about 2,500,000, equivalent to 140,000 new residents each year. The average population density is just over 1,000 inhabitants/km^2 with values ranging between 4,000 and 5,000 in some Italian areas and over 10,000 inhabitants/km^2 in the Istanbul area. There are large stretches of the Greek coast with population densities below 100 inhabitants/km^2. As mentioned earlier, this area is extremely abundant in habitats: there are about 700 sites of the Natura 2000 network for a total of 2,300 km^2, equal to over 25% of the area surveyed. Maintaining, restoring, and safeguarding these habitats are the key points of several policies adopted at European level since 1976 through the Mediterranean Action Plan (MAP), an offshoot of the United Nations Environment Program (UNEP) through which various programs are implemented addressing the scientific, socio-economic, cultural and legal aspects of the protection of the Mediterranean environment. Signed also by non-European countries, this Convention is a regulatory tool to plan measures for the sustainable management of all activities that may have significant adverse effects on the coastal environment. The protection of the marine environment is taken up by the subsequent Marine Strategy Framework Directive adopted by the European Union in June 2008 (2008/56/EC) updated in 2017, and later followed by the EU Recommendation on Integrated Coastal Zone Management (ICZM). The ICZM is a dynamic, interdisciplinary and interactive process to aggregate all policies that have an impact on European coastal regions, planning appropriately both the management of resources and coastal space. Another interesting initiative is the one adopted in 2013, namely a draft Directive, to establish a framework for maritime spatial planning and integrated coastal management in EU Member States, with a view to promoting the sustainable growth of maritime and coastal activities and the sustainable use of coastal and marine resources. It is essential to understand and monitor anthropogenic and natural transformations taking place in these fragile environments. Hence, this paper aims to assess land cover transitions along the coastal arc of the European part of the Mediterranean Sea from 1990 to 2018.

We have conducted our analysis using the NUTS3 administrative level to appropriately assess conditions in each coastal area. This understanding is a fundamental prerogative to guide possible actions/strategies to improve current environmental conditions within the framework of territorial policies to achieve sustainability.

2 Materials and Methods

Land cover maps [23], are derived from the European portal Copernicus (https://www.copernicus.eu/en). The minimum mapping unit (MMU) is 25 ha for areal phenomena and a minimum width of 100 m for linear phenomena. This database covers a 30-year time span (data acquired in the following years: 1990, 2000, 2006, 2012, 2018), with essentially unchanged data genesis. Land cover changes were analyzed through change layers also available in the same repository (MMU 5 ha). Data on the geography of European countries were derived from the EUROSTAT website (updated at 2019 - https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts). The coastline was then extracted from this database. All data used are projected in the ETRS89 LAEA Europe (EPSG: 3035) reference system. The coastal strip was subdivided into 143 plots derived from the geographical and administrative location of the boundaries of the 123 units (Provinces/Districts) in the study area. Each of these plots was assigned an ordinal value (from 1 to 143) from West to East in order to analyze changes in geographical and spatial continuity. Therefore, the value 1 was attributed to the Province of Cadiz in Spain (City of Tàrifa) and 143 to the province of Hatay in Turkey on the border with Syria. The first part of this research focuses on assessing the development of settlements by analyzing urbanization density index and on the changes in surfaces transformed to urban use in the period considered. By urbanized surfaces we mean those intended for urban functions, with the replacement or retention of natural land. This type of surface includes built-up land and areas used for settlement ancillary functions, such as public and private gardens, sports facilities, unpaved roads and other service areas. Suburban roads are excluded from the calculation. These surfaces are the same as those recorded under item 1 in the CLC nomenclature. Settlement pressure, both in its diachronic and synchronic form, was analyzed using the urbanization density index and the urban variation ratio, whose formulas are shown below:

$$\mathrm{UD} = \left(\sum \mathrm{Us}\right)/\mathrm{Au}(\%) \tag{1}$$

$$\mathrm{UVR(Urban\ Variation\ Ratio)} = (\mathrm{Aurbt}_1 - \mathrm{Aurbt}_0)/\mathrm{Aurbt}_0(\%) \tag{2}$$

where:

Us = Urbanized surface
Au = Reference territorial surface

Both indices were calculated in two 2 specific time periods: 1990 and 2018. Index (a) provides information on the degree of existing anthropic pressure while index (b) is linked to settlement behavior adopted by individual administrative units. The latter

provides information on the percentage increase of urbanized surfaces between two distinct time periods compared to the initial condition. In the second part of our research, we analyzed the entire range of land use transitions. We investigated, in particular, land use transformations between two successive time periods (1990–2000; 2000–2006; 2006–2012; 2012–2018). The different types of possible land use transitions are listed below:

Natural - semi-natural - Artificial (from 3 to 1; from 4 to 1; from 5 to 1): change from natural to artificial use (e.g., a wetland converted to urban use);

Natural-semi-natural - Agricultural Use (from 3 to 2; from 4 to 2; from 5 to 2): transition from natural to semi-natural use (e.g., a forest converted to agricultural use);

Agricultural Use - Artificial (from 2 to 1): change from a semi-natural to an artificial use (e.g., conversion of an agricultural area to urban use);

Agricultural use - Natural (from 2 to 3; from 2 to 4; from 2 to 5): this type of transition is tied to the abandonment of farmed areas for example;

Natural - Natural (from 3 to 4; from 3 to 5; from 4 to 3; from 4 to 5; from 5 to 3; from 5 to 4): transition from a natural use to another natural use of a different category (e.g.: from wetland to water body).

Artificial - (Agricultural - Semi-natural - Natural) (from1 to 2 or 3 or 4 or 5): these transitions usually involve the use of de-sealing techniques.

Lastly there are the transitions within the same macroclass. Added to this, we need to consider whatever remains unchanged and the ensuing increases/decreases in surface for each of the different land use classes. All transitions to artificial land use take away fertile soil, are often irreversible, and have additional direct negative impacts in terms of environmental fragmentation, loss of ecosystem services, climate and hydrogeological effects as well as a range of indirect impacts (increased air and noise pollution, increased energy consumption and transport demand…). Conversely, changes from anthropogenic to natural uses obviously have several positive impacts on multiple aspects and help mitigate several risks: increase in vegetation cover, decrease in surface runoff and creation of new habitats for animal and plant species, just to name a few. This type of analysis therefore provides information from both a geographical and a statistical point of view, in order to interpret dynamics and identify the drivers that have modified land use [24–26]. There is a lack of data for Albania for the 1990 period.

3 Results

3.1 Urban Coastal Dynamics

The condition observed in 1990 (hatched grey in Fig. 1) appears distinctly different from that of the present day. In 1990 urbanized areas along the coastal strip amounted to about 1,570 km^2, equivalent to a UD of just over 19%, with areas lacking urbanization concentrated mainly along the northern part of the Italian Adriatic coast and in some parts of Central Macedonia in Greece. There are 18 areas with a UD above 50% (12% of the total) involving a stretch of the Spanish coast (Malaga) and most of the French coastal area, up to and including the entire Ligurian arc in Italy. Similar conditions are also found along large stretches of the Adriatic coastline. In Greece and Turkey, these

urbanization rates are reached in the districts of respective capitals. Furthermore, 75% of investigated areas have a UD below 38%.

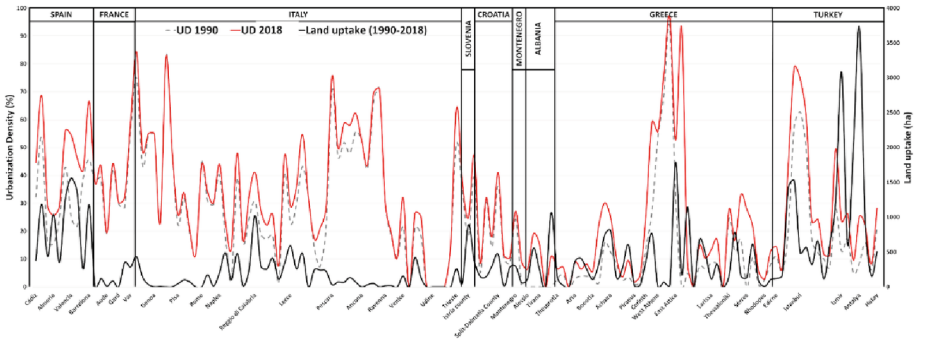


Fig. 1. UD index trend in 1990 (dotted gray) and 2018 (red). Land uptake is also shown (black) as measured over the period considered in each coastal area

Between 1990 and 2018, major urbanization processes affected most of the Greek coastline and some parts of the Turkish coast. The mean value of the UVR index of the entire Mediterranean coast is 35%, while the one of these 2 countries is approximately twofold. In Italy and France this value is much lower than the average. In the case of Italy, this is due to different initial settlement conditions, compared to Greece and Turkey. The transformative drive that substantially changed the appearance of the Italian coastline reached very high values between the early 60's and the late 80's, when settlements eroded significant parts of the coastal system (Romano et al., 2017, 2014). The French coasts already had a significant degree of urbanization back in 1990 (UD > 30%), with the exception of some stretches where settlement processes were limited by morphology. Spain is the only country with an index value in line with that of the Mediterranean area. Among the 12 provinces administering the over 1,500 km coastline, Valencia and Castellón have doubled their urbanized areas, reaching a UD of around 50%. This makes them among the most intensely urbanized areas along the Spanish coast. Among the countries in the Balkan area, Croatia has a UVR value of 20%. Along this coastline, the Split-Dalmatian region has the greatest urbanization, owing to regions with important historical settlements at national level, such as the cities of Split, Solin and Kastel. The northern part of the coast is where the highest values of the UVR index are found: 36% in the Istrian Region, where the flourishing tourist activity has transformed large stretches of the coastline, and 65% in the Lika and Senj Region, but in the latter case transformations are less intense and more localized, due also to the rugged coastal morphology (Fig. 2).

Furthermore, transition matrices were created and analyzed using land cover change data provided by the Copernicus Land Project (Fig. 3).

Between 1990 and 2000 over 12,000 ha of agricultural land were converted to urban use, 70% of which in Turkey and 15% in Spain. As a result, 5.2% of agricultural land present in 1990 was permanently lost. Turkey is the country with the highest conversion rate (1,200 ha/year), followed by Spain (270 ha/year), while Italy and Greece transform their coastal territories at a substantially identical rate (approximately 130 ha/year).

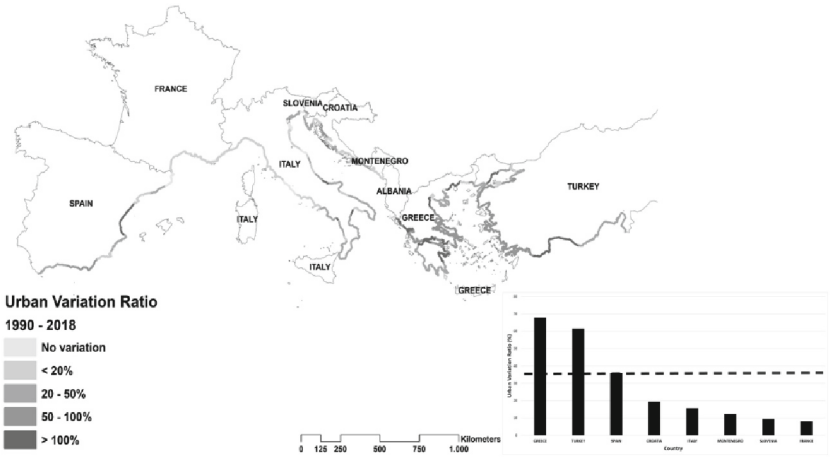


Fig. 2. UVR index values between 1990 and 2018. The dashed black line shows the observed value for the entire Mediterranean coast

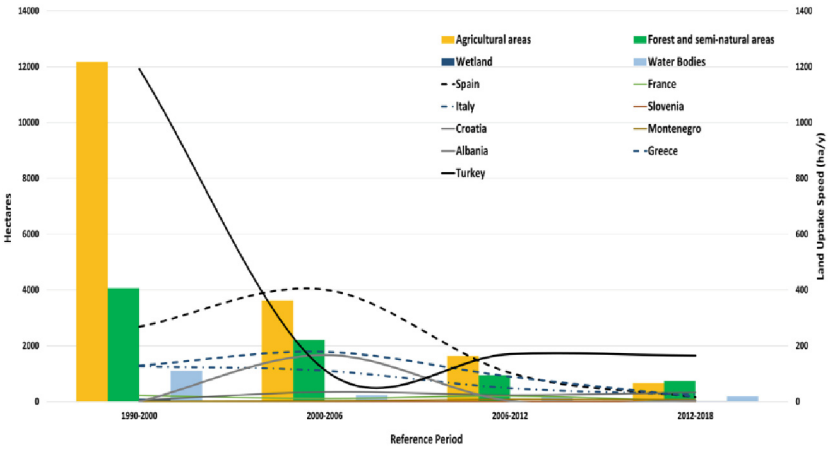


Fig. 3. Land-to-Urban conversion matrix (bars) in the two distinct time periods and land uptake rate trends (ha/year) along the coastlines in the countries considered (lines)

Forests and semi-natural areas are also affected by settlement-related phenomena: 40 km^2 are converted to urban use. Grasslands (21%), sclerophyllous vegetation areas (23%) and, to a slightly greater extent, transitional woodland-scrub areas (25%) are the most commonly transformed. In this case too, most of the transformations have occurred in Turkey (58%), and to a lesser extent in Spain (20%) and Greece (16%). The highest rate of urban transformation of land occurred in this period: 17.5 km^2 irreversibly lost each year. Between 2000 and 2006, there was a slowdown in the transformation drive, with 10 km^2 of land converted to urban use each year. In this period, Spain had the highest rate (4 km^2/year) followed by Greece and Albania (2 km^2/year). Agricultural areas are still the most commonly affected (60%). The downward trend is also confirmed by data

in the following period (2006–2012): approximately 30 km^2 converted to urban use, 60% of which was farmland previously. The yearly uptake rate has dropped further and is halved compared to the previous period. Almost 80% of transformations concerns the coastal areas of only 3 countries (Turkey, Spain and Greece). However, despite the decline, Turkey is the only country where transformation has picked up again since 2006 and where as much as 60% of total forest classes, transformed from 2012 to 2018, have been converted to urban use, followed by Croatia with an alarming 20%. Moreover, maquis is most commonly converted to urban use. Another important aspect is the low rate of land uptake in France (maximum 20 ha/year between 2006 and 2012) with very limited overall land uptake, entirely unlike other Western European countries.

3.2 Land Cover Transitions

Figure 4 shows all possible transitions (analyzed at the first CLC level) together with the number of hectares in the area concerned for each of the countries investigated. The bar chart shows the percentage of transformed land through each transition, compared to total areas undergoing a change in class in each of the countries considered.

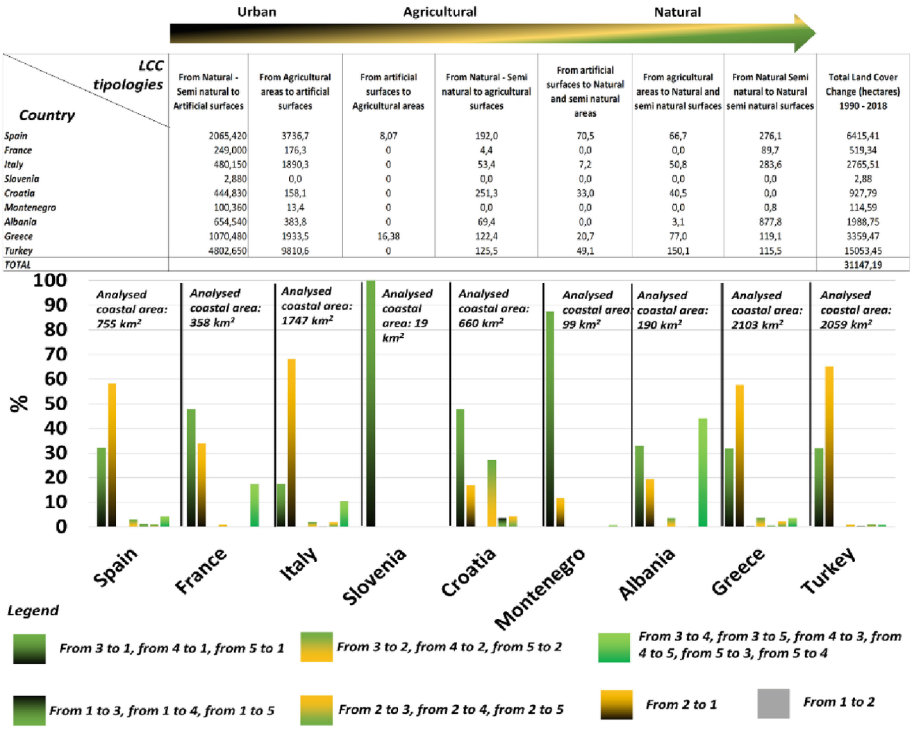


Fig. 4. 1990–2018 transition matrix for Mediterranean coastal areas broken down per country

The table shows that, between 1990 and 2018, 90% of transitions are to artificial land use types, further emphasizing the strategic importance of coasts for settlements.

The country with the lowest figure is Albania (52%), followed by Croatia with 65%. All other countries exceed 80% and Turkey, Montenegro and Slovenia had only transitions to artificial land. Additional anthropic transitions include those to agricultural classes. These transformations certainly have a greater degree of reversibility compared to the former, but the areas affected are still subject to significant anthropic pressure that could further exacerbate water supply-related issues. 900 ha are affected by this type of transformation, most of which in Croatia (30%) and Spain (22%). Abandoned farmland and pastures or transitional natural vegetation are what characterize transitions from any type of land cover to a natural one. This type of transition has concerned only 7.5% of total transformations, most of which were concentrated in Albania (about 880 ha), a very high figure if compared to Italy (340 ha), Spain (413 ha) and Turkey (312 ha) that have vaster coastal expanses. This is mainly due to consolidated economies linked to the tourist industry in Italy and Spain and the significant growth of this sector in Turkey since the early 2000s linked to strong public and private investment [27–29] stimulated by the steady increase in the number of tourists. In order to provide a more detailed territorial picture, this system of transitions has been analyzed at the NUTS3 level (Fig. 5).

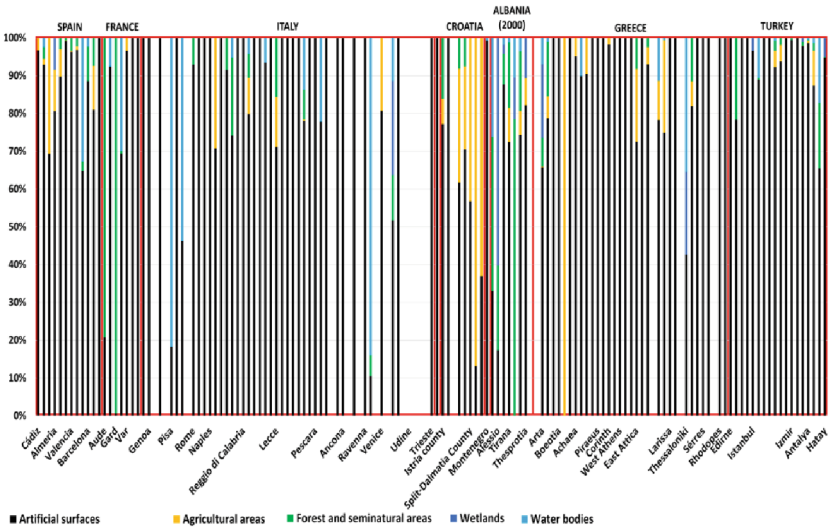


Fig. 5. Land cover transitions expressed as percentages of total transformed areas between 1990 and 2018 for each of the NUTS3 levels analyzed

In all Spanish coastal areas, the prevailing transition is towards artificial land uses, whose percentage is never below 65% of the total. Significant transitions to other types of land use may be found in the provinces of Granada (31% farmland) and Tarragona (33% water bodies). As far as French coastal areas are concerned, the important transitions to natural land uses in the Departments of Aude and Gard are due to Natural Parks (Narbonnaise en Méditerranée Natural Regional Park) and Natura 2000 sites which have curbed the less intense transformation drive affecting other areas. Of the 54 areas analyzed along the Italian coastline, 26 (approximately 50%) have transitioned to urban

uses only, while few areas have been converted to farmland, mainly in the provinces of Salerno and Lecce. Important transitions to natural land uses can be found in the Province of Catanzaro and in the previously mentioned Salento region. The coastal areas in the Croatian regions are marked by a higher percentage of changes to agricultural use of land. Most of these are concentrated in the Dubrovnik-Neretva County, an area scarcely affected by mass tourism, which instead is mostly concentrated in the northern part of the country and its islands. The situation in Albania is more intricate: major transitions to artificial land uses may be found in the counties of Shkodër (87%), Tirana (73%) and Korcë (75%), while significant transitions to natural land uses concern the coastal territories of Gjirokastër (79%) and Durrës (41%). The Greek coastal areas have similar dynamics to the Italian ones, although the settlement process drive is greater. Indeed, 700 ha of land have been converted to urban use in Greece, with 18 of the 37 areas analyzed transitioning only to CLC class 1. Transitions to natural land are not very significant and are found only in the Aetolia-Acarnania region (15% of the total) and in the Chalkidiki region (12%). Transitions to agricultural uses are slightly more significant, accounting for the only transition in the West Attica territories (100%) and for 20% of transitions in the areas of East Attica and Magnesia Prefecture. Turkey does not differ much from the country with which it borders on the Thracian Sea. Transitions to natural land uses reach at least 20% of the total only in a couple of areas (Çanakkale and Adana).

4 Discussion

Our research has analyzed land cover transitions in the Mediterranean coastal system over the last 30 years. The entire analysis was conducted using CLC data available for the entire European continent over several time periods. However, the methods used for the cartographic acquisition of CLC data (MMU 25 ha and minimum width of linear elements equal to 100 m) do not make it possible to detect all dispersed settlements [30] present in some of the countries analyzed, such as Italy, Spain, Albania and Greece. Many new settlements (residential or tourist accommodation) have the typical characteristics of sprawl [31, 32] (particularly evident along the Turkish coast), due to obvious reasons tied to economic return, but in many coastal areas, settlements can be ascribed to the sprinkling model owing to their building density and extremely low coverage ratios [33–36]. This type of settlement is often developed spontaneously or subject to poor land-use planning control, compounded by the lack of underlying urban planning, making it extremely impactful from the standpoint of landscape, energy, land consumption and management costs.

Our work shows that in approximately 30 years over 550 km^2 have been urbanized with a linear land uptake rate equal to 40 km/year. However, based on our previous remarks, this figure could be significantly higher. It is therefore clear that given the different geographic, typological-functional and morphological characteristics of settlements in some European countries, data having greater cartographic detail would be needed in order to properly monitor urban development. Clearly even change layers, whose MMU is equal to 5 ha, are unable to detect these changes because this pervasive form of settlement has the size of a single building or of aggregates of a few units (Fig. 6). The analysis has also highlighted that coastal areas are subject to intense and



Fig. 6. Examples of sprinkling along the coastline in some countries in the investigated area

continuous anthropic pressure over time. The significant tourist attractiveness of places together with one of the most favorable climates globally (mild winters, long summers and an ideal atmospheric temperature range) have intensified settlement and agricultural transformations largely altering extensive coastal areas. These 2 types of transitions account for over 90% of transformations in countries such as Spain, Croatia, Greece and Turkey where this figure nears 98%. Italy and France are just below this threshold with 88% and 82% respectively, while Albania is the only country where transitions to natural land cover have reached high values (45%). Coastal areas with strong urban dominance (DU $>$ 40%) account for 31% of the total. These are areas undermined by urban development where nature is often relegated to residual interstitial spaces between buildings and infrastructure. They are found along almost the entire Spanish coastline, in the coastal arc that goes from Var (France) to Liguria (Italy) and along the Tyrrhenian Sea in the areas of the coast of Rome and the Gulf of Naples. Calabrian coastal areas, both Tyrrhenian and Ionian, also share the same characteristics, while along the Adriatic it is the western part that is in more critical conditions, especially the area from upper Abruzzo to the coast of Romagna. Along the eastern part, similar conditions are found only in the Primorje-Gorski Kotar county and Split-Dalmatia County. Although Greece and Turkey are the countries with the greatest land uptake for urban use during the period analyzed, they have few areas in these conditions: the Athens-Piraeus area, in the case of the former and the Istanbul and Balikesir area, in the case of the latter. Many of the settlements found today along the Turkish coast are of recent construction, linked to the growing tourist attractiveness of these places [37] and have affected many of the coastal forest areas [38, 39]. Unlike what has happened in other countries in the Mediterranean area, these settlements are entirely designed in accordance with appropriate regulations that limit the maximum height of buildings and protect archaeological areas and natural habitats.

5 Conclusion

This research work is the first, at international level, to investigate natural and anthropogenic transitions affecting over 16,600 km of Mediterranean coastline in the past 30 years. Despite limitations tied to CLC data acquisition techniques for urbanized areas, our research highlights the strong transformational pressure that coastal territories are subject to, due to their important role in both local and national economies. Moreover, the use of NUTS3 administrative boundaries has helped us understand which coastal areas are mostly jeopardized by anthropic transformations, where environmental rehabilitation and habitat restoration are very difficult to implement due to the considerable pervasiveness of settlements. This could help foster more detailed studies on these areas to investigate the actual distribution of built-up areas and their function in the broader geographical context, in order to implement appropriate policies and targeted actions. In this regard, correct Integrated Coastal Zone Management (ICZM) depends greatly on an efficient monitoring system capable of detecting in real time any transformative processes threatening coastal areas. Satellite imagery already help us obtain data with the necessary geometric accuracy, while available technologies help process huge amounts of data very quickly. It is therefore appropriate to implement a console of indicators (environmental, urban, ecological and demographic) capable of providing quick feedback on the actual conditions in each of the European coastal areas, connected to an early warning system for any potential risks caused by incorrectly planned transformations.

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