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Carolina Signorelli [(1)], Luca Di Giorgio [(2)]

ASSESSING URBANIZATION TRENDS ON ELBA ISLAND (TUSCANY, ITALY): A DIACHRONIC ANALYSIS FROM 1956 TO 2011

Abstract - C. Signorelli, L. Di Giorgio, *Assessing urbanization trends on Elba Island (Tuscany, Italy): A diachronic analysis from 1956 to 2011.*

Assessing land use dynamics is pivotal in understanding how societal shifts and economic changes manifest on the geographical canvas over time. Hence the analysis and monitoring of land use is important to comprehend the interchange between human activities and the environment. In this study, a diachronic analysis is carried out of the change in the area covered by built-up land in a period from 1956 to 2011 of the entire area of Elba Island, the largest island in the Tuscan Archipelago, Italy. There has been a major socio-economic change in it during the above period, which, according to previous studies, has altered the island's landscape over the last fifty years. The change from an agricultural economy to one concentrated on mass tourism has resulted in the abandonment of rural areas and the expansion of urbanization, mainly affecting areas along the coastal strip. This study aims to identify and show exact quantitative data regarding the increase in the built-up area, with particular reference to the elevation measures at which increased construction activity has occurred. Accurate territorial analysis can be carried out by processing data with open-source software. Through processing with QGIS software it was possible to quantify the building change on the island of Elba between reference periods, as well as the functional areas around the buildings. Quantifying and understanding the anthropic influence of the edified areas on the surrounding ones is important to evaluate their environmental impact, particularly in regions highly affected by activities with a high economic interest.

Key words - Tuscan archipelago, Elba island, Italy, urbanization, Mediterranean ecosystems, territorial analysis, tourism impact, QGIS, diachronic analysis

Riassunto - C. Signorelli, L. Di Giorgio, *Valutazione della tendenza di urbanizzazione dell'Isola d'Elba (Toscana, Italia): un'analisi diacronica dal 1956 al 2011.*

Analizzare le dinamiche dell'uso del suolo è di vitale importanza per comprendere come i cambiamenti socio-economici si manifestano a livello geografico nel corso del tempo. Il monitoraggio dell'uso del suolo ci aiuta a capire inoltre l'interazione fra le attività antropiche e l'ambiente. In questo studio abbiamo effettuato un'analisi diacronica sulle variazioni riguardo alla superficie edificata dell'intera Isola d'Elba, la più grande isola dell'Arcipelago Toscano. Il periodo preso in esame abbraccia gli anni dal 1956 al 2011: in questo arco temporale si sono verificati cambiamenti economici e sociali che, in linea con studi precedenti, hanno modificato la struttura paesaggistica. Un'economia prevalentemente agricola ha lasciato il posto ad una concentrata sul turismo di massa, con la seguente espansione delle aree cittadine costiere a discapito delle zone rurali. Lo scopo di questo studio è di identificare e mostrare i dati quantitativi riguardo all'aumento dell'area edificata sull'isola, focalizzandosi inoltre sulle altitudini alle quali si è svolta l'attività edilizia. Analisi territoriali accurate possono essere portate avanti con i software open-sources. Abbiamo usato il software QGIS per quantificare la variazione di edifici dell'Isola d'Elba nel periodo di riferimento, così come l'area funzionalmente edificata attorno agli edifici. Un processo di questo tipo è importante per valutare correttamente l'influenza antropica sulle aree naturali circostanti, specialmente in quelle regioni molto interessate dall'attività economica..

Parole chiave - arcipelago toscano, Isola d'Elba, Italia, urbanizzazione, ecosistemi mediterranei, analisi territoriali, impatto del turismo, QGIS, analisi diacronica

Introduction

Building construction and the resulting soil consumption are major global problems because they cause severe landscape disturbance and intensify human pressure on the environment worldwide (Winkler *et al.*, 2021). Estimates of the level of squatting in Italy in 2011 show that there is still a clear tendency to perpetuate the abuse of land and soil, especially in sensitive areas of higher landscape value such as coastal areas (Istat, 2019).
This tendency began last century with the construction of large infrastructures, roads, and railways (Fierro, 1999) and increased concurrently with the evolution of mass tourism in the territory (Salizzoni, 2012).
According to ISTAT data, in 2011 the Italian territory showed an urbanisation index of 29.8 buildings per 100 km^2. Between 2000 and 2010, coastal areas alone registered about 34500 new residential buildings (Istat, 2019). This erosion of rural space reflects the broader progression of urban sprawl, which increased nationwide from 19.9% in 2001 to 22.2% in 2011 (Istat, 2019).
These national dynamics are particularly significant in insular and coastal contexts, where limited space and fragile ecosystems amplify the pressure of human activities (Delanoë *et al.*, 1996). Although it is not specified how much this trend affects Elba Island in par-

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ticular, in recent decades, due to increasing touristic pressure, urbanisation has increased especially along the island's coastline, which has revealed functional consequences for the ecosystem of the area (Carta *et al.*, 2018). In addition, the presence of roads, which are increasingly frequent because of heightened construction, contributes to increased coastal erosion (Cipriani *et al.*, 2011).
However, rather than textbook sprawl (where the city spreads around), in the case of Elba, it may be more a question of habitat fragmentation and overbuilding caused by the construction of homes, second homes, and functional connecting buildings, with related consequences for the environment and landscape. The extent, total impact, and precise extent of development on Elba, both today and over the years, requires study and monitoring.
The economic interests of the local community related to the exploitation of natural resources and coastal tourism is a phenomenon with a very important impact, especially during the high season (Sessa, 2022). These case histories constitute the greatest dissent towards government nature protection regulations (Bonaiuto *et al.*, 2002) causing significant impact of human activities on the environment. Coastal erosion on Elba Island depends mainly on regional factors in different land use rather than environmental factors such as wind direction or the influence of sea currents (Cipriani *et al.*, 2011). The increase in mass tourism that has occurred in recent decades on Elba Island has had consequences, such as increased beaches, mobility problems due to crowding compared to the number of permanent inhabitants (Sessa, 2022), and the construction of buildings.
In the flat area of Campo nell'Elba, the easternmost isthmus characterizing the island's morphology, a small airport was build with mainly touristic purposes. This fact demonstrates the importance of the tourism for the island but testify, also, the impact on the nature and the landscape, and the human occupation of the land.
There is uncertainty about the possible impacts of this intensity, considering the possible land-based consequences that such a trend may have, as possible impacts on the natural environment. The biodiversity present in Elba, the fact that the Mediterranean basin is among the most altered biodiversity hot-spots (Myers *et al.*, 2000), its environmental vulnerability as an 'island system' (Fernández-Palacios *et al.*, 2021; Lavorel *et al.*, 1998) and the advent of probable future influences from global warming (Blondel, 2010) determine the gravity in having to implement more accurate urban management plans and effective conservation strategies as soon as possible, trying to mitigate the contrast between interventions for nature conservation and local economic strategies, mainly based on mass tourism (Dapporto & Dennis, 2008).
In this context, a better understanding of the dynamics of urban expansion becomes essential, since reliable data are the first step towards sustainable territorial management.
Therefore, the main aim of this work is to quantify the urbanization trends on Elba Island within a defined time span (1956-2011) through a diachronic approach. The objective is to provide a quantitative overview of the island's built-up expansion across different altitudinal zones, offering a replicable framework for monitoring future land use changes both on Elba and in other Mediterranean island contexts.

Study area

Elba is the largest island in the Tuscan Archipelago and the third in Italy, after Sardinia and Sicily (Canestrelli, 2024). It is bordered by the Ligurian Sea to the north, the Piombino Channel to the east, the Tyrrhenian Sea to the south, and the Corsica Channel to the west. The island has a surface area of approximately 223.5 km^2 and a coastline of 147 km (Ferrari, 1990), with a morphology that is distinctly elongated along its east-west axis (27 km) compared to its north-south width (18 km).
One of the island's most distinctive features is the complex geological structure, which has long attracted scientific attention, since the beginning of the 1800's. The first conceptual geological model of Elba Island dates back to the mid-20th century, describing the island as composed of several tectonic plates that overthrust one another during the Apennine orogeny (Trevisan 1950, Trevisan 1951). This model was later refined by subsequent studies, confirming the island's position between the Tuscan and Ligurian paleogeographic domains (Bortolotti *et al.*, 2001; Carmignani *et al.*, 1995). Thanks to this rich history of research, Elba's complex geology continues to attract scientific interests, just in the last year, several studies have been dedicated to Elba's geology or mineralogy (e.g., Andreozzi *et al.*, 2025; Papeschi *et al.*, 2025; Brogi *et al.*, 2025).
The island can be divided into three main morphological sectors, separated by two low Quaternary isthmuses. The central sector is characterized by gentle hills of sandstone and limestone, traditionally cultivated, whereas the western and eastern sectors are steeper and more rugged. The island's coasts are generally high and rocky, sometimes forming cliffs that are actively eroded by the sea, and slope instability is frequent (Centamore *et al.*, 1988).
Within this varied morphological framework, the island exhibits a complex geological structure where metamorphic, sedimentary, and intrusive rocks coexist. Among these, the large granodioritic pluton of Monte Capanne (1018 m a.s.l.) dominates the western

sector, while the smaller La Serra-Porto Azzurro pluton characterizes the eastern area and is genetically linked to the formation of ancient iron deposits.

The climate of Elba Island can be classified as predominantly Mediterranean with semi-arid characteristics. Water availability is generally low, particularly during the summer months and in the eastern sector of the island. This seasonal drought often causes water stress in vegetation, increasing its vulnerability to wildfires, which periodically affect the island (Rapetti, 2009). Together, geomorphological and climatic gradients determine the island's ecological zonation, creating a mosaic of nearly three bio-climatic zones (Foggi *et al.*, 2006). The habitats' variety host exceptional biodiversity, including rich plant life (Lavorel & Richardson, 1999; Cowling *et al.*, 1996), a diverse fauna with numerous biotopes, and several endemic species (Peruzzi & Carta, 2011; Dapporto & Dennis, 2008; Dapporto & Cini, 2007; Médail & Quézel, 1997; Greuter, 1991).

Despite its delicate natural characteristics, the island has been profoundly shaped by human activity since ancient times. Mining has played a particularly important role: first exploited by the Etruscans (6th century BCE) for its iron deposits, Elba served as a mining center for more than three millennia (Corretti, 2017).

This long-lasting activity influenced the island's socio-economic development and left a geological and mineralogical inheritance of scientific value, contributing to the advancement of mineralogical studies (Ispra, 2009). Last mine closed in 1981 (Corretti, 2017), not because the deposits were depleted, but because of technical mining difficulties that made its exploitation disadvantageous in terms of cost. The cessation of this primary activity, coupled with the abandonment of rural practices, resulted in significant changes to the landscape, including the advancement of higher vegetation over former cultivation fields (Carta *et al.*, 2018).

After the closure, several local initiatives were launched to protect and enhance this unique heritage. In 2001, the Elba Island Mining and Mineral Park was established. Today, the Park includes the Mineral and Mining Art Museum in Rio Marina and a network of geo-mineralogical trails located within the former mining areas of Rio Marina-Rio Albano and Calamita-Ginevro (Ispra, 2009). Some mines, such as the Calamita mine in Capoliveri, now open to tourism and considered a strategic iron reserve, belong to the Italian state.

The island's history is not defined solely by mining. It was a Roman Province (Casaburo, 1997) (some villas, such as the Villa delle Grotte, Portoferraio, are still visible) and saw an important demographic and settlement development during the rule of the Grand Duke of Tuscany, Cosimo de' Medici (Piga, 2017) who built walls and bastions in the town of Portoferraio. During his exile in 1814, Napoleon carried out reforms that initiated major economic development (Hicks, 2014).

Despite a long history marked by changing dominations, maritime conflicts, and even pirate raids, Elba has largely maintained the integrity of its landscapes over time. Such continuity can be attributed to traditional land management practices, which, like in many other Mediterranean regions, allowed for land use and resource exploitation without severely altering natural ecosystem cycles (Blondel, 2006). However in the last fifty years, the landscape pattern of Elba has changed a lot, following the transition from a mostly agricultural economy in the late 1800s to mass tourism from the 1960s to the present (Vogiatzakis *et al.*, 2008). As a result of this recent shift, the human impact over the island shaped the vegetation composition in a heterogeneous manner on the island (Carta *et al.*, 2018, Garamanti *et al.*, 1997).

The coastal environment is highly sensitive and vulnerable (Delanoë *et al.*, 1996), making it a priority for nature conservation. On Elba Island, a National Park was established in 1996, limited to certain areas of the island, about 50% of the territory, and leaving out the most populated ones. The Park area includes most of the areas of historical-mineralogical and geo-mineralogical heritage. Beyond the areas managed by the National Park, several other conservation zones have been designated. The Special Protection Area "Elba Orientale" (Natura2000 code: IT5160102) was established in 2007, although as of 2020 it still lacked an approved management plan. The Special Protection Area "Monte Capanne and Promontorio dell'Enfola" (Natura2000 IT5160012) has existed since 1995, with its plan officially approved in 2022. Finally, the wetland area "Zone umide del Golfo di Mola e Schiopparello," only partially included within the National Park, is recognized as a Site of Community Importance but not yet part of the Natura 2000 network. This site remains particularly vulnerable due to coastal erosion, illegal dumping, land-use changes, and scattered urban development near its boundaries. There is no management plan but there are several documents attesting to different proposals for the recovery of the site. Part of the protected area is in fact affected by urbanized areas, landfills, and agricultural areas.

This Island's history highlights both the ecological importance and the fragility of the place, where urban expansion and tourism pressure coexist with valuable natural habitats. However, despite the presence of protected areas, detailed quantitative assessments of soil consumption and its distribution across different altitudinal zones remain limited. This study aims to fill this gap by providing a multitemporal analysis of building expansion between 1956 and 2011. The results are expected to support future research and provide decision-makers with useful data to balance urban development and the conservation of biodiversity in island environments.

Table 1. Source Files for GIS Analysis of Building Cover Across Historical Periods.

File	**Format**	Institution
Edificato 1956	WFS	Regione Toscana - SITA: Cartoteca
Edificato 1978	WFS	Regione Toscana - SITA: Cartoteca
Edificato 1988	WFS	Regione Toscana - SITA: Cartoteca
Edificato 1996	WFS	Regione Toscana - SITA: Cartoteca
Edificato 2011	WFS	Regione Toscana - SITA: Cartoteca
DTM	RASTER	GEOscopio
Parco Nazionale dell'Arcipelago Toscano	RASTER	GEOscopio

Methods and analysis

The study area includes the entire surface of the island. The files used for this study are open source, and available on the site of regional organisations (Table 1). They are Web Map Service (WMS) layers, a standard protocol for serving georeferenced map images over the internet, provided on the site of the Tuscany Region (SITA-Cartoteca, https://www502.regione.toscana.it/geoscopio/cartoteca.html) with the GEOscopio service. The layers were opened and analysed in the open-source QGIS spatial processing software (QGIS, 2021).
Geoscopio Cartoteca is an online platform managed by government agencies for the free consultation of cartographic elements, georeferenced maps, orthophotos, and thematic maps. It is a useful tool for conducting research over long periods of time, as in this study. The maps are free to download because the service is open source, making them easy to use for studies and analyses such as this one.
We elaborated all data on open-source software QGIS 3.16.3-Hannover. For this study, the period after 2011 was not considered due to a lack of open-source WFS data. The layers downloaded are correlated to five specific historical periods (the years 1956, 1978, 1988, 1996, and 2011) each representing the distribution of building cover in that year. The data was available with service WMS on QGIS (http://www502.regione.toscana.it/ows2/com.rt.wms.RTmap/wms?map=owsedificato&map_resolution=91). The layers considered are: rt_edif.sedime_edificato.1956, rt_edif.sedime_edificato.1978, rt_edif.sedime_edificato.1988, rt_edif.sedime_edificato.1996, rt_edif).
The multitemporal analysis was necessary for a correct examination of reference parameters' variation on the territory. We didn't take the metadata relating to the type of building, the date of construction, the intended use, and the height of the buildings into consideration for this analysis. Through a conversion, each layer has been made geo-processable for the related analyses. We also considered Corine Land Cover data (WMS, Geoscope) for discussion.

Variation of building coverage by historical period

We searched for WMS each layer (rt_edif) to obtain the number of elements for chronological data, and to count the actual increase in new construction projects performed through the years. We analysed the variation in building coverage (in m²) and its expansion over time for each layer and calculated the total area covered by all the buildings. They were then arranged in a matrix to demonstrate the change in building coverage over time and analysed on an external software (using Excel tools), to verify what was built in the various historical periods. It was, therefore, possible to obtain demonstrative graphs of the trend of building coverage on the Island of Elba and to be able to make a percentage comparison between the area covered by buildings (initially without considering whether they are residential or other types of buildings) and the area that is not. A subsequent consideration regarding the not-buildings-covered area was made: this study doesn't consider all the anthropogenic coverage and influence of the buildings, but only the coverage of them. It means that the "free area" could be covered by roads and communication routes, city spaces (car parks, squares, port platforms, etc.) and other buildings (temporary constructions, bathing sites, etc.).

Variation of building coverage due to elevation

We compared the data obtained to the elevation of the area, to verify whether the building extension encountered technical difficulties in expanding into areas characterised by challenging building conditions due to steep slopes or mountainous terrain, or if it affected only the flat or coastal areas. To do this, we used open-source Digital Terrain Model (DTM) data (http://wms.pcn.minambiente.it/ogc?map=/ms_ogc/WMS_v1.3/raster/DTM_20M.map).
We began by establishing three altitudinal zones, defined based on their distinct functional and morphological characteristics. Zone 1 (24,7%) contains the latitudinal strip in contact with sea level, including the entire coastal strip from 0 m a.s.l. up to 50 m a.s.l.;

zone 2 (38.9%) is between 50 m a.s.l. and 190 m a.s.l, there are residential areas, urban and service areas and most of the communication routes; zone 3 (36.4%) is the whole latitude band above 190 m a.s.l. It includes urban areas with a good part of hilly area, and the mountainous part, in which there are no urban areas. Each building in our dataset was then assigned to one of these three zones based on its elevation. The municipalities of the study area were also categorized according to their average altitude, providing a broader geographical context for the analysis (Fig. 1).

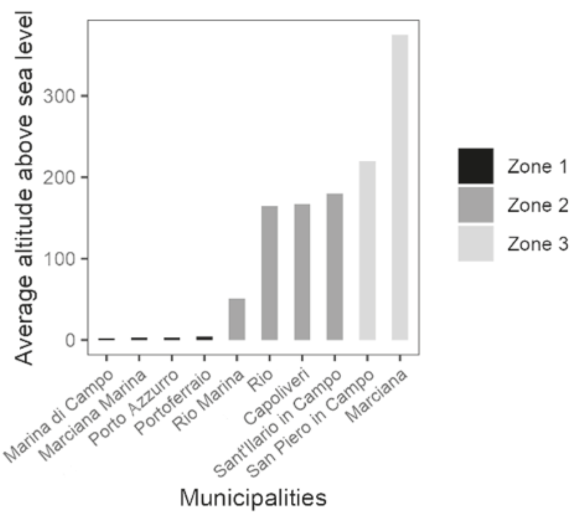

Figure 1. Municipal subdivisions based on altitude zones. Altitudinal zones depict specific elevation ranges, showing the geographic distribution within the study area: Zone 1 (0-50 m a.s.l.); Zone 2 (50-190 m a.s.l.); Zone 3 (>190 m a.s.l.).

Finally, the total built-up area for each altitudinal zone and historical period was calculated and organized in a spreadsheet. This framework allowed us to quantify and compare the temporal variation in building expansion relative to topographical constraints.

Comparison with Corine Land Cover

The 'total built-up area' metric is limited as it only considers the physical footprint of the buildings themselves. It fails to account for the surrounding, functionally connected land cover (such as access roads, courtyards, and parking lots, etc. but do not include all the paved roads and other communication routes on the island) that are also part of the structure's overall impact. Measuring this larger disturbed area would provide a more faithful understanding of the pressure exerted by each building on the landscape. Relying solely on a building's footprint underestimates its true spatial impact. To better analyse this component, the Corine Land Cover (CLC), provided by ISPRA of Tuscan Region (https://groupware.sinanet.isprambiente.it/uso-copertura-e-consumo-di-suolo/library/copertura-del-suolo/corine-land-cover), was used. It's an open-source tool useful for evaluating the functional trend of an anthropized territory. We compared the surface of CLC with the total edified area. The result indicatively provides an 'area of influence' that is interested in functional building necessity, but not in building coverage. These data were also compared with the total area of the island, obtaining an estimate of the area directly influenced by the built-up per year. Subsequently, the data was analysed in comparison with the building site of the closest date. At the time of the analysis of this study, three layers were available, relating to the years 1990, 2000, and 2006. We geoprocessed them and compared them to the building layers of the years closest to those dates, i.e. 1988 with CLC 1990, 1996 with CLC2000, and 2011 with CLC2006. The areas taken into consideration for each CLC were: residential areas with continuous fabric and discontinuous and sparse fabric; road networks and technical infrastructures, port areas, recreational and sports areas, areas mainly occupied by crops with the presence of complexes, cropping systems and parcels complex. The latter were included in the analysis due to the 'sprinkling' phenomenon (Romano *et al.*, 2017), present above all in some extra-urban areas, such as Campo nell'Elba (personal observation). These areas, which develop around the main centres or the beaches, do not however include all the buildings present on the island, as there are also houses in the wooded and scrub areas.

Results

Variation of building coverage by historical period

Using the multitemporal (1956-2011) WMS layers described in the methodology, we quantified the evolution of the building stock on Elba Island. The spatial distribution of building cover across the five historical periods shows a progressive expansion from the mid-20th century to the early 21st century (Fig. 2).

Our analysis revealed a drastic increase from 5215 buildings in 1956 to 39682 in 2011, corresponding to a 661% increase (Fig. 3). The most significant growth occurred between 1996 and 2011, with 25706 new buildings actualized in that 16-year period, an average of approximately 1607 buildings per year.

This trend can be seen in all municipalities, with different sizes (Fig. 4). Marciana Marina and Porto Azzurro are the Municipalities with the lowest number of buildings built (mean variation for these Municipalities = an increase of 1372.5 buildings), while the other Municipalities (Capoliveri, Campo nell'Elba, Portoferraio, Marciana) there is a higher increase (mean change in

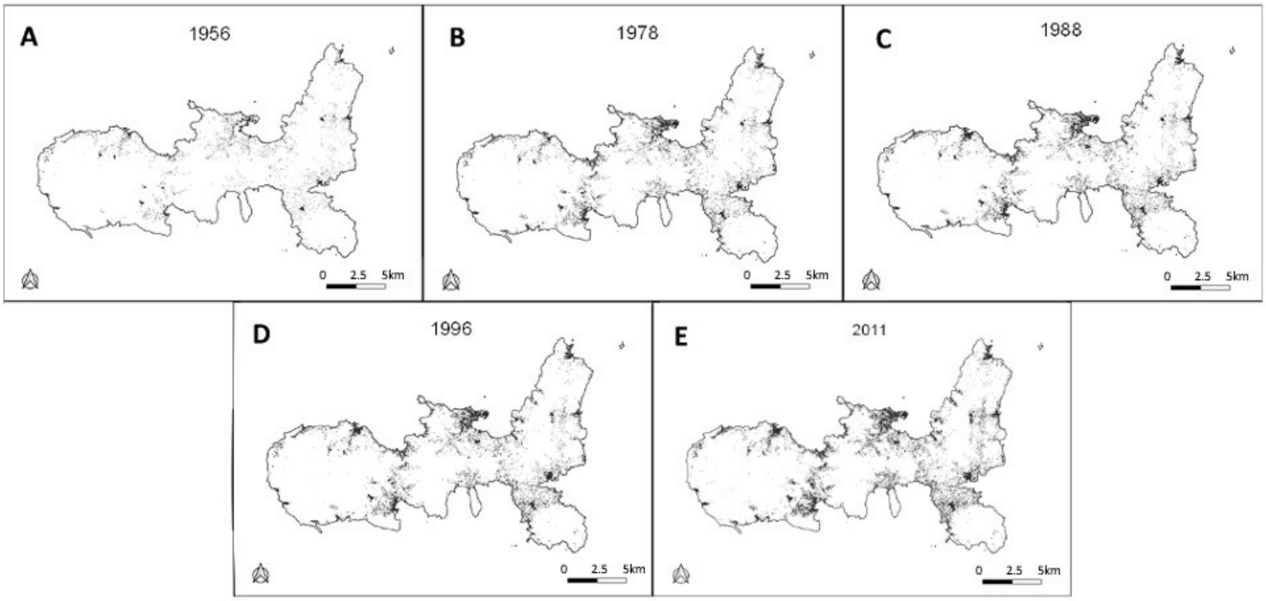

Figure 2. Temporal Dynamics of Building Cover on the Island. Spatial evolution of building cover on the island is depicted across five distinct historical periods in sub-figures (Fig. 2 A-E).

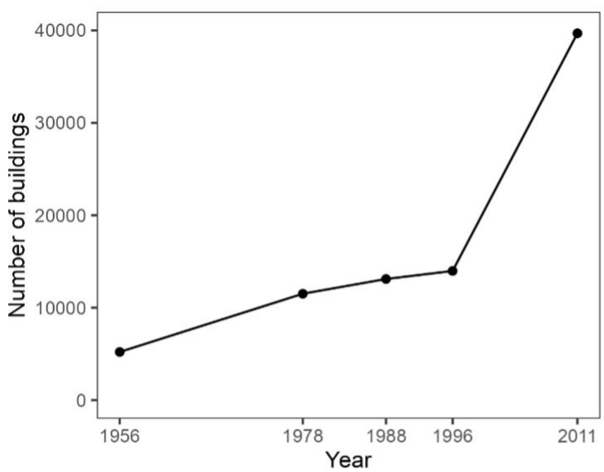

Figure 3. Number of buildings variation within the study area across the selected five-year periods.

these Municipalities: a variation of 4993.5 new buildings). However, the municipality Rio ranks at an intermediate level in terms of the annual number of buildings constructed (variation with 2987 new buildings).
The municipality with the largest increase in the number of new buildings constructed is Capoliveri, with a total increase of 1096% in 2011 compared to the beginning; followed by Campo nell'Elba with 1012%, Portoferraio with 645%, Marciana with 501%, Porto Azzurro with 488%, Marciana Marina with 474%, and finally Rio with 470%. The total coverage of built-up land in 2011 was 2.75 km^2, almost four times as much as the total coverage in 1956 (0.72 km^2). Over the whole Island, the percentage change increased by 282%. The municipality that has experienced the greatest growth in coverage in square kilometres is still Capoliveri with an increase of 5.28 times in 2011 compared to the initial condition in 1956. It is followed by: Campo nell'Elba (3.5), Portoferraio (2.95), Rio (2.18) and Marciana (1.81). Measuring the ratio of the area affected by building coverage to the total area of Elba Island, it appears that 1.22% of the area was occupied by construction, in 2011. The municipality with the highest ratio for the entire period is Marciana Marina (increased by 1.73%), followed by Capoliveri (increased by 1.08%), Portoferraio (increased by 1.40%), Porto Azzurro (increased by 1.12%), Campo nell'Elba (increased by 0.58%), Rio dell'Elba (increased by 0.90%).
Also the higher increase of edified surface corresponds to the last historical period examined. A difference can already be noted between the Portoferraio area and that of the other Municipalities which, on the other hand, were similar in terms of number of buildings (Fig. 5).
About the total area of the Municipality (Fig. 6A), Marciana Marina is the most affected, with a more important variation between 1978 and 1988. The greatest variations occurred between 1956 and 1978 for Portoferraio, Campo nell'Elba, Porto Azzurro, Marciana, and Capoliveri. The other variations are quite linear and the increase in the number of buildings reported by the other results does not appear so marked, especially for the period 1996-2011. We also elaborated the ratio of the parameters with the total surface for the Municipality (Fig. 6B).

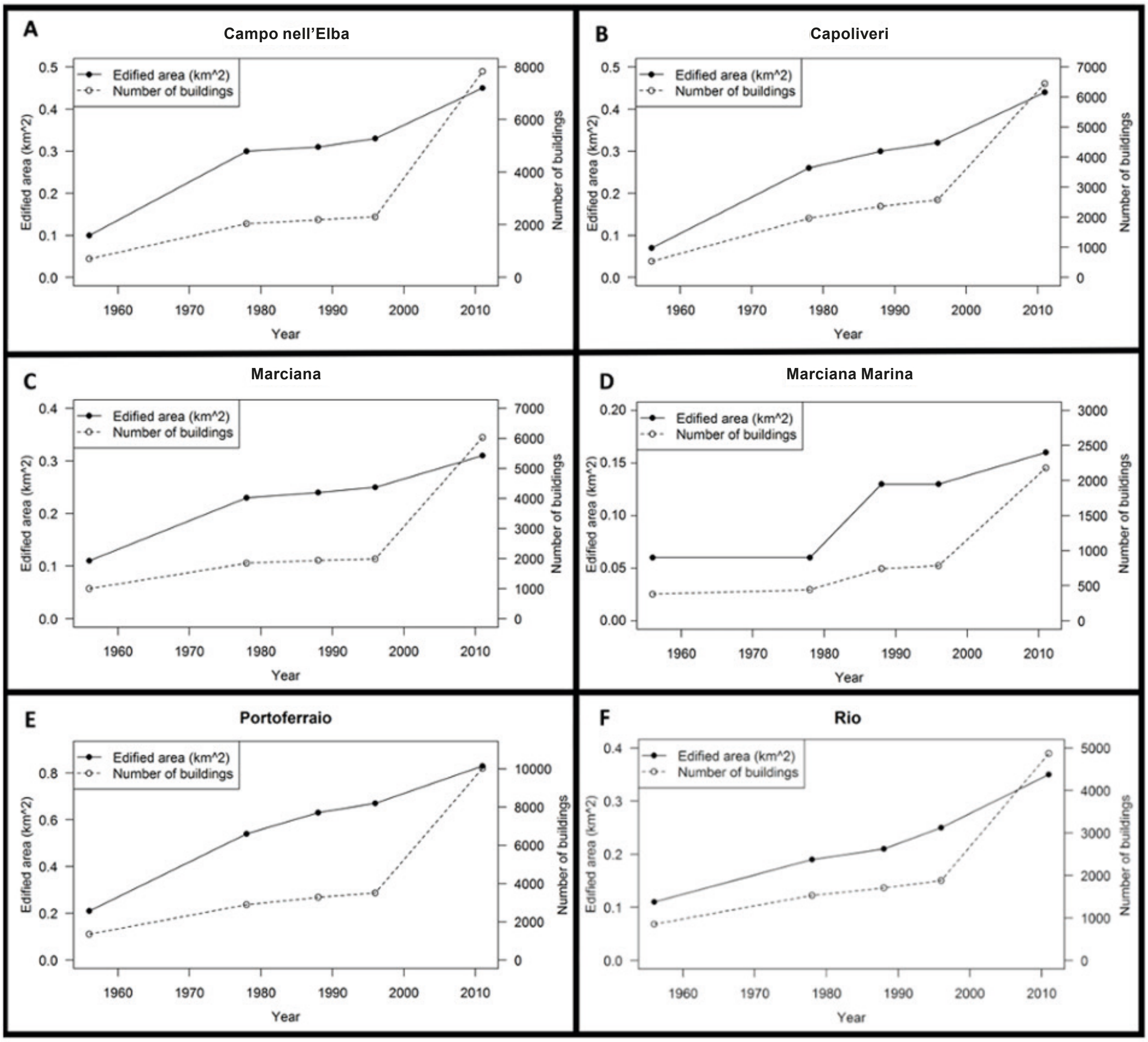

Figure 4. Relative edified area and number of buildings over the years in each municipality.

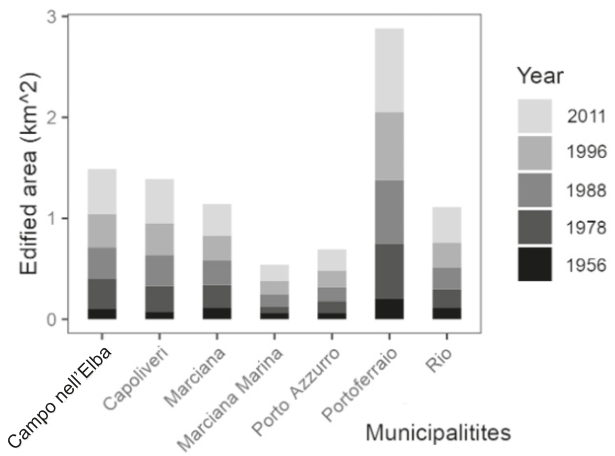

Figure 5. Temporal trends in absolute edified area in km² for each of the six Municipalities over the specified years.

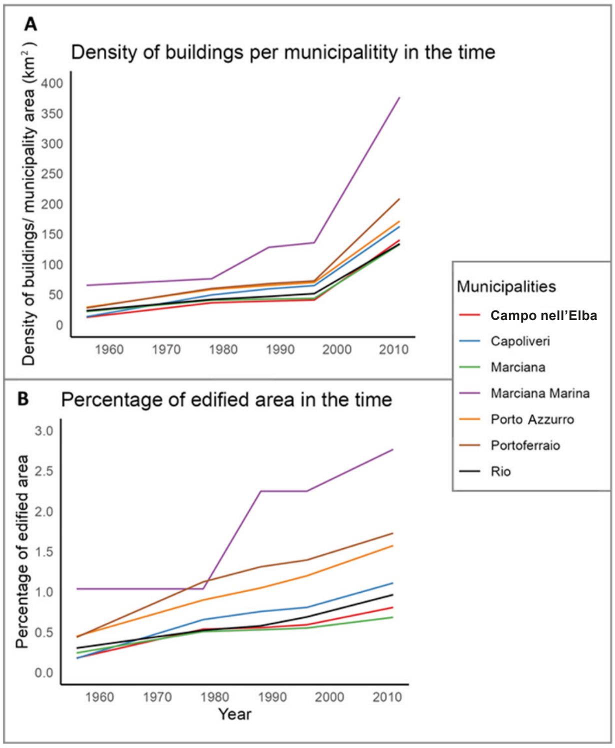

Figure 6. Temporal Trends in Building Density (A) and Percentage (B) of edified area across Municipalities on Elba Island.

Variation of building coverage through elevation

Following the subdivision into altitudinal zones (Fig. 1), we analysed the distribution of buildings and built-up surface in each class over time.

The temporal evolution of building numbers across the three altitudinal zones is presented in Fig. 7 providing a clear visualization of the construction trends. The corresponding numerical data for the number of buildings are available in Table 2, while the data for the total area of built-up land cover and its percentage of the total surface of each altitude subdivision are presented in Table 4A and Table 4B, respectively.

This analysis highlights that the area most affected by the construction process is Zone 1, including the entire coastal strip. In 1956 and 2011, Zone 1 had more than half of the total buildings in those given historical periods. In 1956 Zone 1 had 3340 buildings and 0.49 km^2 covered; in 2011 it had 26681 buildings and 1.98 km^2 covered. The most significant variation in this altitude range occurred between 1956 and 1978, with an increase of 6.06% for the number of buildings (and congruent with an increase of 5.83% for the area covered). Zone 2 (between 50 and 190 m a.s.l.) had 1508 buildings in 1956 and in 2011, 10506. For the total area covered by building land, in 1956 it had 0.18 km^2; in 2011, 0.64 km^2. In this altimetric zone, the most significant change in this altitude range occurred between 1996 and 2011, with an increase of 6873 buildings (and an increase of 0.19 km^2 coverage).

In 1956, Zone 3, which continues from 540 meters a.s.l. to the highest peak (Monte Capanne, 1019 m), had 359 buildings, which increased to 2491 in 2011. In 1956, this area had an area covered by buildings of about 0.06 km^2 while in 2011 of about 0.12 km^2.

In particular, this zone underwent an increase in the number of buildings during 1996-2011, with an increase of 6873 compared to the mean of the variations that occurred in that zone in the other years, corresponding to an increase of 708.33. The most significant variation for this altitude range occurs, for built-up coverage, between 1956 and 1978, with an increase of 0.03; about the number of buildings, the greatest change occurs between 1996 and 2011 with an increase of 1853.

All the graphs show a coherent tendency regarding the number of buildings, i.e. that the greatest variation occurred between 1996 and 2011 in all zones.

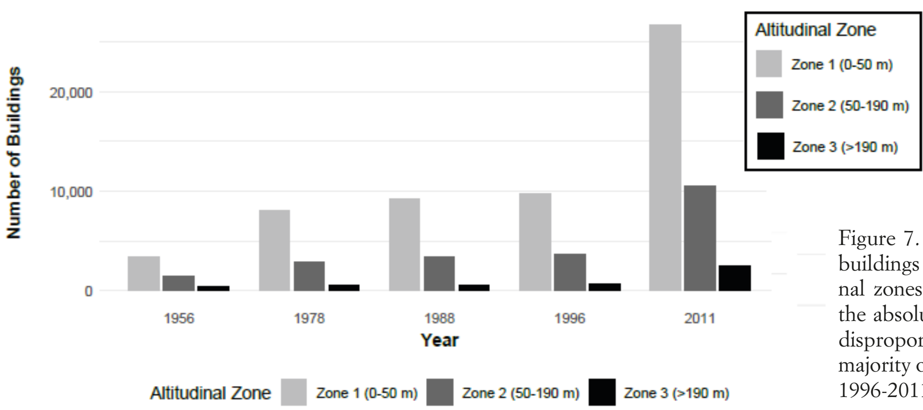

Figure 7. Temporal evolution of the number of buildings (1956-2011) within the three altitudinal zones. While all zones experienced growth, the absolute increase in Zone 1 (0-50 m a.s.l.) is disproportionately larger, accounting for the vast majority of new buildings, particularly during the 1996-2011 period. This highlights the intense pressure of urbanization on the coastal strip.

Table 2. Number of buildings across three altitude zones over the five years under examination.

	Zone 1	Zone 2	Zone 3
1956	3340	1508	359
1978	8044	2914	546
1988	9153	3351	592
1996	9712	3633	625
2011	26681	10506	2491

Table 3. Edified Area, Corine Land Cover (CLC) and remaining land area of Elba Island.

	1988-1990	1996-2000	2006-2011
Edified area in km^2	1.96	2.11	2.75
Corine Land Cover (edified area excluded) in km^2	42.01	42.03	43.4
Remaning Elba surface in km^2	180.03	179.86	177.85

Table 4. Distribution of built-up Areas across Altitudinal Zones on the Island of Elba. Table 4A presents the absolute values of built-up areas, expressed in square kilometers (km^2), within the three distinct altitudinal zones over five years. In Table 4B, the values are represented as percentages relative to the total surface area of each altitudinal zone. This perspective offers insights into the proportional extent of built-up areas aiding in assessing spatial development patterns and land use dynamics across the island.

A	Built-up areas (km^2)		
	Zone 1	Zone 2	Zone 3
1956	0.49	0.18	0.06
1978	1.26	0.36	0.09
1988	1.47	0.41	0.09
1996	1.58	0.45	0.1
2011	1.98	0.64	0.12
B	**Built-up areas (% of zone area)**		
	Zone 1	Zone 2	Zone 3
1956	0.79%	0.20%	0.10%
1978	2.04%	0.40%	0.14%
1988	2.38%	0.46%	0.14%
1996	2.55%	0.51%	0.16%
2011	3.20%	0.72%	0.20%

Comparison with Corine Land Cover

To better contextualize the built-up dynamics, we compared our results with Corine Land Cover data (1990-2006), following the approach outlined in the methods.

With this analysis, we found indicatively the areas interested by anthropic influence around the buildings, excluding the built-up coverage. The CLC data available show an area for the zones of our interest that are: for 1990, 43.97 km^2; for 2000, 44.14 km^2; for 2006, 46.15 km^2. These data were compared with the total area of the island, obtaining an estimate of the area directly influenced by the built-up per year (Table 3). Subsequently, the data was analysed in comparison with the building site of the closest date. For the 1988 buildings and the 1990 CLC, there is 0.87% of actual built on an area of land use linked to this use of 19.62%, with 42.01 km^2 of area directly interested by built-up (not covered by the building site). For 1996 buildings and 2000 CLC data, we have 0.94% and 19.70%, with 42.03 km^2 of area directly affected by built-up. For the buildings of 2011 and the CLC data of 2006, it is 1.22% out of 20.60%, with 43.4 km^2 of area directly affected by built-up.

Discussion

The data show a gradual growth in the number of buildings, which intensified in the period from 1996 to 2011.This represents a continuation and acceleration of localized trends of urbanization already identified by the late 20th century in certain districts like Porto Azzurro and Marciana Marina and Capoliveri (Garamanti *et al.*, 1997). Our data suggest that this previously localized phenomenon has become a more widespread driver of landscape change. The progress of the number of buildings corresponds to an equal number of building permits approved and implemented.

The percentage ratio between the built-up area and the number of buildings is 0.42%, which would indicate the prevalence of buildings of modest square footage. This could be particularly represented in the Municipality of Capoliveri, for which the number of buildings (over the totality of the periods considered) increased by almost 1100% despite the area affected by built-up roofing being 1.1% compared to the total area of the Municipality. Many small buildings have less impact than one large building, but their number could have a high impact in terms of habitat fragmentation due to their dispersion over the territory. The study analyses only the extent of the building roof and not the surfaces affected by built-up connected to it, such as roads and passageways, courtyards and gardens, other general anthropic surfaces, and anything that isn't free land.

The relationship between the built-up area and the area of the Municipality itself, in fact, is useful for understanding the percentage of coverage concerned concerning the total area, without distinguishing between non-buildable areas (steep areas, …) and areas already occupied by functional activities (roads of communication, car parks, squares, etc.).

Regarding the expansion of the building site per km^2, all the Municipalities have undergone an increase of more than double the coverage built in 1956.

The discrepancy between the actual built-up area and the functional urban impact areas (provided by the Corine Land Cover) shows that the impact of the building is more represented by the area around it than by the surface covered by built-up buildings.

These areas found with our study are, respectively, 42.01, 42.03, and 43.4 km^2 of difference as the impact area of the buildings, i.e. the surface not covered by buildings but where it represents a direct influence, as or areas with waterproofed soil (concrete, asphalt, stone, etc.) or areas where human presence is permanent.

This comparison draws attention to the greater change in the number of buildings than a change in the total area occupied by the buildings. This is consistent with a scenario where there is a dispersion of buildings, mostly homes or "second homes", with little impact from the point of view of the landscape, with some exceptions, but potentially harmful to the fragmentation of the territory and human disturbance associated with each building.

To provide a concrete visual example of this urban dispersion, we selected the coastal municipality of Marciana Marina (belonging Zone 1), which our data identifies as one of the areas with the highest building density. A comparison of orthophotos from 1954 and 2019 (still sourced from the Geoscopio portal, Regione Toscana) for this area tangibly illustrates the building expansion described quantitatively (Fig. 8). While a systematic orthophoto analysis was unsuitable for an island-wide assessment due to the scale of the phenomenon and data heterogeneity, this example highlights the significant landscape impact of concentrated construction. This visual evidence supports our concern regarding habitat fragmentation and underscores the need for future studies to quantify its effects on local biodiversity and natural resources.

In general, the fragmentation of the territory due to urbanised areas, and connection roads between them, can represent a disturbing factor for the dispersion of species and therefore for ecosystems (Laurance & Yensen, 1991). Although a measure of habitat loss in this way is mandatory for human needs, an excessive intensity of this disturbance could have very negative effects (Fernández-Palacios *et al.*, 2021; Wilcox & Murphy, 1985), especially if carried out abusively and without adequate controls.

Zone 1 of altitude is the most built-up cause of the fact that most of the activities and services, both tourist and non-tourist, are concentrated along the coast. Zone 1 experienced the greatest surge in the change in the number of buildings between 1956 and 1978, during the period of mass tourism development. While Zone 2 and Zone 3 are the most affected by this variation in the last period, between 1996 and 2011. This is consistent with the increase in built-up areas discussed above.

The ratio between the area covered by buildings and the total area by altitude range always shows rather low numbers (Table 4), but this doesn't consider the total land use coverage, which could indicate the variation of the increase of building on some areas for lack of 'space on which it is possible to build'. Another factor that could have explained a shift in the increase in building from Zone 1 to Zone 2 couldn't be the scarcity of space, but rather the presence, in some places, of steep coastal areas unsuitable for building or construction of passageways.

Actions for the conservation of natural spaces are important everywhere, but mostly in susceptible places such as island systems, where anthropic disturbance factors can be more harmful to most vulnerable species (Ruzzier *et al.*, 2021; Fenu *et al.*, 2020).

On Elba Island, the interest for the conservation of natural areas and species had practical feedback later than the beginning of the period considered in this study. This may have generated consequences for which there is no data, and which cannot be quantified, such as the loss of habitat or damage to a certain species.

As far as we now, there are no direct studies on the impact of buildings on certain natural aspects. However, as has been written previously, a greater building concentration can be closely correlated to a wider range of secondary disturbances, which derive not only from the direct effects of the buildings (e.g., soil impermeabilization) but from the zones of influence closely linked to them.

It is known from the profile of the ZPS 'Elba Orientale', they appear as "real risks for conservation: urbanization and artificialization of part of the coastal and agricultural territory (coastal road axes, widespread residential building), with forecasts of further expansions".

Furthermore, previous studies of incidence (e.g. Nemo, 2009) carried out on the Elba island have reported the "presence of urbanized areas and communication routes and the possibility of a further increase in accommodation capacity" as external criticalities, and as a management proposal for the orientation of the "urban management of the municipalities towards the recovery and reuse of the historic housing stock and the containment of land consumption (with a drastic reduction of new expansions and scattered built-up areas in the absence of a balanced use of the existing stock").

This last sentence is also recurring in the lists of critical issues in other areas since urban development appears to be an inevitable phenomenon due to tourist and consequently economic pressure. The hypothesis of further urban development, with a consequent increase in the pressure of tourism and anthropic disturbance, can represent a threat not only to the consumed

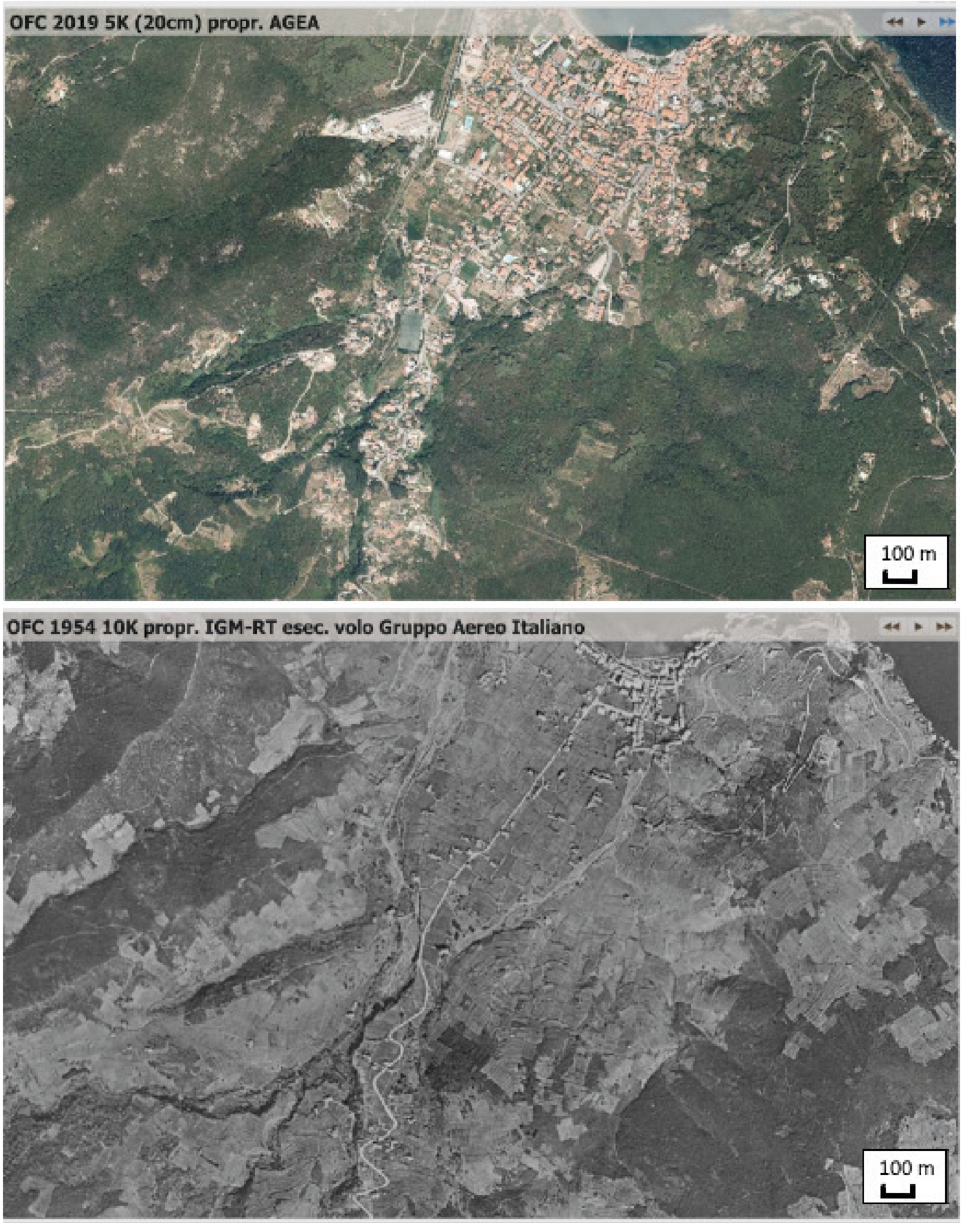

Figure 8. Visual comparison of urban expansion in Marciana Marina. (Top) A 1954 orthophoto (Flight: Italian Air Group) sourced from the Geoscopio portal (Regione Toscana). (Bottom) A 2019 orthophoto (AGEA) from the same source. The notable stylistic differences between the historical and modern imagery are due to the evolution of aerial survey techniques over the 65-year interval. While these specific years fall slightly outside the core study period (1956-2011), they provide the best available visual evidence to illustrate the long-term landscape transformation and the increase in building density characteristic of a Zone 1 municipality.

soil but also to the neighbouring areas and not directly affected, including the environments protected by plans for conservation. The real scenario could be worse considering that human pressure generates the greatest damage due to tourism, which has a strong seasonal component in Elba. It is already known that this represents a problem in particularly sensitive natural areas such as beaches and dunes (Flamini, 2016). The high population concentrations that are recorded during the high season on the island of Elba as an excellent tourist destination creates uncontrolled consequences and often with destructive effects on the environment, plus ultra than only edification disturbance.

Conclusion

This study has provided to obtain and analyse the data specifically related to this territory, and relate them to other parameters to deepen the possible engines of an expansion.

We see that in the period from 1956 to 2011 the variation of the built-up area on Elba Island changed, consistently with the socio-urban attitude of the territory, reported by other studies.

However, it is an evident conclusion that further expansion and dispersion of buildings could seriously threaten the environment and irreparably disfigure the

characteristic landscape of Elba island. For this reason, the present study wanted to report precise data, to focus on a trend that if uncontrolled can be harmful. The analysis of variations of built on portions of land is possible using open-source software. The employed methodology enables straightforward replication of the study type in various locations or urban settings. This to constitute a diachronic and complete analysis for several territories, to be combined with the evaluation of other parameters with which to compare data.
The phenomenon of land consumption for building is constantly increasing and affects the entire territory of Italy, although in a uneven way, as often reported by the environmental reports of the sector. In the case of the island of Elba, more than the amount of area covered by buildings, the dispersion of buildings and the resulting fragmentation of habitat due to the route-affected areas and functional areas around these buildings may be of concern in terms of impact, that in different ways are affected by consumption phenomena. Understanding the influence of functional areas around buildings is important to determining their environmental impact. This is especially valid in areas affected by the uncontrolled spread of urban plants and consequent fragmentation of the habitat.
In conjunction with the activity of the Tuscan Archipelago Park for the conservation of the territory, further studies are needed on the effects of anthropic disturbance on the environment, the application of territorial quality indices and better management that regulates urban dispersion on the island, as well as incentives to distribute the tourist pressure for most of the year and decrease its seasonality. This is in the interest of perpetuating sustainable tourism and preserving the heritage of Elba Island, as it should be for all of Italy, naturalistic but also cultural and social.

Conflict of interest statement

The authors did not receive grants from funding agencies in the public, commercial, or not-for-profit sectors for this research. We declare no interest conflict.

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