WHAT DRIVES BUILT-UP AREA EXPANSION ON ISLANDS? USING SOIL SEALING INDICATORS TO ESTIMATE BUILT-UP AREA PATTERNS ON AEGEAN ISLANDS, GREECE

THANASIS KIZOS, GEORGIOS TSILIMIGKAS & SOFIA KARAMPELA

University of the Aegean, Department of Geography, 81100 Mytilene, University Hill, Greece.
E-mails: akizos@aegean.gr; gtsil@geo.aegean.gr; karampela@env.aegean.gr

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ABSTRACT
The dispersion of built-up areas in peri-urban zones is considered an important, almost irreversible environmental threat, especially in coastal zones and islands. In this paper, we use soil sealing datasets derived from the European Environment Agency in order to estimate the expansion of built-up areas in the North and South Aegean islands in Greece. We examine these differences in relation to socio-economic features of the islands, especially tourism development, second home development and size and geographical position of the islands. The findings show divergent levels of soil sealing and a variety of spatial configurations, such as scattered growth of built-up land in coastal areas and peri-urban growth in rural areas. Higher cover of the total area of islands by sealed soil is related to tourism, but it seems that second homes are also an important driver, especially for smaller islands located relatively close to Athens. From a planning and management perspective, these findings can assist local or regional administration to assess the effectiveness of land use management plans and manage flows and processes.

Key words: Land use, land cover, soil sealing, spatial metrics, North and South Aegean islands, Greece

INTRODUCTION

Urbanisation has been one of the most important socio-economic processes globally in the last centuries (Kourtit *et al.* 2014), transforming societies, economies and the environment around the world, and encroaching upon nearby areas (Brenner & Schmid 2013). This encroachment can be either linear (i.e. along transportation lines or along the seafront), organic (i.e. around the historic limits of settlements), planned (i.e. after some kind of land use plan) or scattered (i.e. unprogrammed and unplanned urban development in the countryside) (Salvati & Morelli 2014). In the Mediterranean region, the expansion of built-up areas is a particular problem along the coasts, where rapid urbanisation is associated with the expansion of tourism (Benoit & Comeau 2006).

Despite differences in definitions according to size, population, location, etc., islands form a special kind of space. There are some common features that make them a distinct category of space: 'islandness' (Baldacchino 2007) includes both 'real' features of islands, such as small size and isolation, as well as 'imagined' features, such as the special 'experiential quality' of islands (Royle 2001). For

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many islands, the existence of large urban areas has been a historical characteristic, usually due to their nodal place in local, regional, and/or global networks of communication and transport, and driven by population dynamics, economic specialisation and technological change (Salvati *et al.* 2015). However, the recent growth of tourism, along with urbanisation processes, has contributed to the significant increase of urban areas, encroachment upon coastal and rural areas, and the general expansion of built-up space (e.g. Pons *et al.* 2014 for the Balearics; Delis 2014 for an Aegean island). Another relevant notion is that of 'coastalisation' or 'coastality', which can be defined as the attractiveness of space with respect to sea proximity. According to Kiousopoulos and Stathakis (2009), this is directly related to residential development in the last two centuries, especially in relation with sea visibility.

The rise of second homes on many islands (Walters & Duncan 2014; Hall 2015) has also led to extended urban growth and sprawl. This increase of built-up areas is critical on islands not only because of its volume, which is excessive in certain cases, (e.g. Salvati 2013; Pons *et al.* 2014) especially compared with the total area of the island, but also because of the character of the areas it has developed upon. Urban sprawl has typically involved coastal zones, panoramic view areas, and areas in proximity to architectural cultural heritage, such as monuments, among others. The intense seasonality of tourism and second home flows (Kizos 2007) increases the amount of pressure on limited island resources. This seasonality makes the impacts on islands even more acute (European Commission 2012) and can seriously degrade already built-up areas such as traditional settlements, as well as affecting the islands' countryside, coastlines, resources, etc. (Tsilimigkas *et al* 2014).

In this paper, we seek to examine what drives the expansion of built-up areas on islands, using as a case study the North and South Regions Aegean Islands (Greece), comprising in total 43 inhabited island municipalities. These islands have experienced deep socio-economic changes in the last decades, with intense depopulation in the 1950s to 1980s for all but a handful of islands, and rapid but very unequal tourism and second homes development afterwards (Karatzoglou & Spilanis 2010). At the same time, the expansion of built-up area was driven by the considerable difference in profits from selling land for building compared to profits from agriculture or any other land use (Spilanis *et al.* 2009). As a result, all land on these islands has been treated as real estate in the last decades. This has led to many small scale private interventions that took place in an unmanaged and chaotic way in many places, and which have had cumulative effects. The land use and building framework is very strict in and around existing 'traditional' settlements, but in many cases this framework is not regulated properly for a variety of reasons, which will be discussed below. Therefore, from a planning perspective, the comparison between different cases (islands) can provide input to local and regional administrations about the effectiveness, or otherwise, of these regulatory frameworks, and management and planning directions. Has this imposed system of strict regulations resulted in a more organised and planned space?

We use soil sealing as an indicator for built-up area expansion and examine its extent and its pattern (shape complexity and aggregation) using data provided by the European Environmental Agency (European Environment Agency (EEA) 2014). We relate soil sealing indicators with a number of socio-economic characteristics of the islands, including population, tourism density and building stock indicators (especially empty houses). Accessibility is another factor that is potentially important for islands in general, and particularly the case study islands, although links between accessibility and built-up area expansion are not established in the literature. Previous research in the area (Karampela *et al.* 2014, 2015) illustrates the complexity of the transportation system and passenger choices. This complexity makes it difficult to adequately capture the factor of accessibility with a single indicator; for example accessibility from Athens would not include many inter-island nodes and links,

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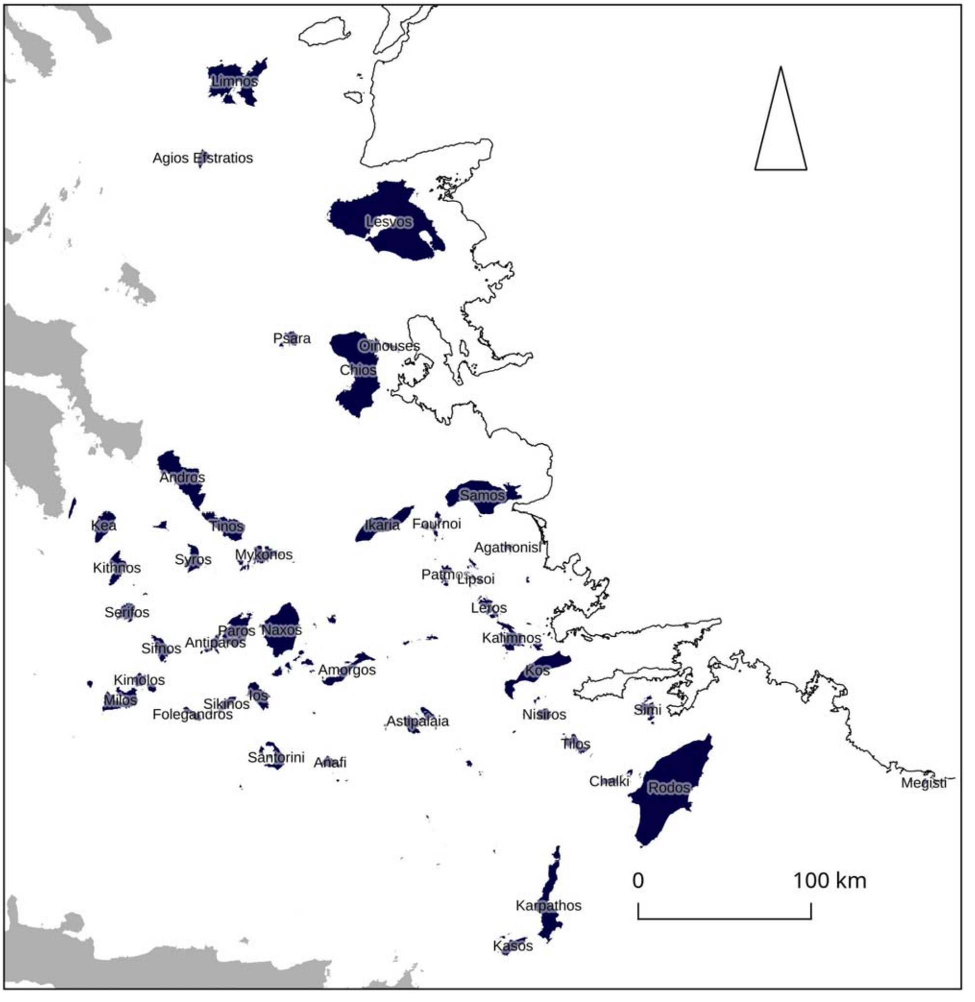

Figure 1. *North and South Aegean Islands. [Colour figure can be viewed at wileyonlinelibrary.com]*

especially from nearby bigger islands to smaller 'satellite' ones.

METHODS AND DATA

Case study area – The cases examined are islands of the North & South Aegean administrative regions. These regions include 57 islands in total, 43 of which are administrative units (and used as case studies in this paper, Figure 1) in the Greek State and 14 of which are very small with few inhabitants. Of the 43 larger islands, 9 are from the North Aegean and 34 from the South Aegean. The islands are diverse: their size varies from 14 to 1,600 km^2 and their population from 180 to 150,000 people (Table 1). The diversity extents to other physical and socio-economic features: geology, relief, precipitation, land cover, population ageing, available services and tourism flows among others.

Historically, the development of settlements on the Aegean Islands has followed the overall political and economic changes in the archipelago. In antiquity, the location of settlements was dictated by the presence of natural harbours and protection from prevailing winds (NE *meltemi*), and very often modern settlements are built above and around

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Table 1. *Values of indicators for the islands*

Islands Municipalities	Population 2011	Surface (km^2)	Sealed cells (km^2)	Build-up (*100 km^2)	Island soil sealing (%)	Compactness (Standardised Value)	Tourist density (tourist arrivals/km^2)	Tourist density (tourist arrivals/population)	Empty houses 1991/Total houses %	Empty houses 2011/Total houses %	Houses built after 1991 percentage of 2011 houses	Empty houses 1991-2011%	Number of patches (NumP)	Greatest patch area (GrPA, km^2)	Edge Density (ED, Km)	Patch Density (PD, 1/Km^2)
Agathonisi	186	14.42	0.02	1.68	0.25	0.00	158.63	12.30	30.77	33.3	29.52	75.00	8	0.01	73.6	230
Agios Efstratios	249	42.10	0.02	7.36	0.24	2.59	60.90	10.30	56.12	56.6	15.28	22.56	2	0.08	31.7	20
Amorgos	1,950	127.41	0.25	7.44	0.26	−0.90	686.37	44.85	54.31	57.3	20.43	48.85	52	0.06	67.2	151
Anafi	294	40.62	0.03	7.44	0.26	2.05	247.53	34.20	60.60	26.0	20.09	−35.52	9	0.06	52.2	81
Andros	9,128	381.40	1.52	90.36	0.64	−0.45	334.88	13.99	55.62	61.0	26.31	40.39	534	0.14	74.5	225
Antiparos	1,196	45.36	0.17	23.84	0.92	0.67	no data	no data	62.04	71.7	54.87	164.30	65	0.16	62.9	157
Astipalaia	1,270	113.37	0.17	20.32	0.33	0.43	297.46	26.55	61.28	60.7	26.27	31.59	44	0.14	56.7	111
Folegandros	787	32.48	0.05	9.96	0.48	1.34	1,012.45	41.79	65.14	58.7	31.98	15.25	17	0.10	60.9	107
Fournoi	1,343	45.88	0.10	0.32	0.31	−0.89	259.29	8.86	48.59	53.9	18.27	46.02	13	0.10	50.8	90
Ikaria	8,431	254.69	0.56	3.86	0.37	−0.31	230.62	6.97	54.94	55.6	18.22	29.06	154	0.13	69.7	162
Ios	2,084	109.77	0.30	16.16	0.42	−0.54	916.79	48.29	56.91	52.7	25.68	28.43	98	0.14	71.6	208
Kalimnos	16,073	134.28	1.01	105.44	1.54	0.21	65.91	0.55	42.58	43.5	19.58	29.98	193	0.80	55.2	93
Karpathos	6,748	323.83	1.00	125.00	0.70	0.53	270.21	12.97	58.00	62.9	24.48	66.01	148	0.49	51.9	65
Kasos	1,070	70.18	0.12	6.80	0.28	−0.53	83.59	5.48	48.21	66.7	7.61	134.16	27	0.06	63.5	139
Kea	2,480	148.78	0.55	64.52	0.81	0.40	455.12	27.30	70.40	74.6	49.01	72.98	235	0.10	71.6	197
Kimolos	901	55.81	0.14	2.92	0.31	−1.02	445.60	27.60	69.25	67.3	10.66	21.10	8	0.14	50.7	47
Kithnos	1,436	99.92	0.26	5.40	0.32	−1.03	450.90	31.37	67.93	76.7	29.81	59.16	45	0.05	66.9	134
Kos	46,099	288.13	3.99	263.84	2.30	−0.34	3,182.13	19.89	34.72	32.0	31.38	63.80	947	0.39	63.9	143
Leros	7,925	75.62	0.67	28.20	1.26	−0.70	353.09	3.37	41.46	45.1	20.78	47.34	208	0.13	77.0	217
Lesvos	86,312	1.639.11	8.13	794.52	0.98	0.13	125.71	2.39	44.61	46.2	17.11	19.69	1,042	2.06	46.2	65
Limnos	16,743	478.55	4.33	374.76	1.69	−0.04	129.01	3.69	43.36	51.3	25.62	61.20	379	1.17	41.3	47
Lipsoi	784	17.22	0.11	5.40	0.96	−0.60	481.63	10.58	48.79	53.3	34.39	91.09	37	0.04	79.7	229
Megisti	496	11.71	0.04	11.08	1.31	2.60	277.46	6.55	56.59	62.7	29.50	158.62	6	0.01	44.4	38
Milos	4,966	167.63	0.84	43.76	0.77	−0.56	626.30	21.14	51.15	55.9	16.41	46.31	82	0.39	52.5	64

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Table 1: Continued

Islands Municipalities	Population 2011	Surface (km^2)	Sealed cells (km^2)	Build-up (*100 km^2)	Island soil sealing (%)	Compactness (Standardised Value)	Tourist density (tourist arrivals/ km^2)	Tourist density (tourist arrivals/ population)	Empty houses 1991/ Total houses %	Empty houses 2011/ Total houses %	Houses built after 1991 percentage of 2011 houses	Empty houses 1991-2011%	Number of patches (NumP)	Greatest patch area (GrPA, km^2)	Edge Density (ED, Km)	Patch Density (PD, 1/ Km^2)
Mykonos	14,189	105.79	3.53	836.88	11.25	2.20	5,115.59	38.14	51.63	60.1	41.90	150.00	735	2.14	49.6	61
Naxos	19,303	498.34	1.25	103.56	0.46	−0.10	655.54	16.92	58.74	60.1	34.22	51.54	316	0.51	61.6	137
Nisiros	1,003	49.81	0.04	10.00	0.29	1.91	no data	no data	57.99	61.2	10.06	40.60	9	0.08	35.4	61
Oinouses	796	17.80	0.11	5.60	0.95	−0.59	155.81	3.48	61.78	47.3	10.16	−26.27	23	0.08	65.9	133
Paros	13,694	198.43	1.74	117.92	1.47	−0.32	1,211.17	17.55	65.22	58.2	38.11	16.42	660	0.19	76.5	223
Patmos	3,477	44.93	0.34	16.32	1.13	−0.62	797.78	10.31	52.67	56.0	24.87	53.61	112	0.12	76.9	222
Psara	412	44.76	0.09	7.24	0.38	−0.20	77.40	8.41	55.97	40.2	20.12	−43.10	3	0.16	44.6	18
Rodos	152,538	1.408.75	9.60	827.6	1.27	−0.04	1,385.91	12.80	32.95	34.2	28.15	52.06	2,029	1.98	60.2	114
Samos	33,339	480.05	3.68	167.24	1.12	−0.65	424.90	6.12	47.45	48.3	22.46	22.54	464	0.39	53.2	87
Santorini	17,752	90.49	2.33	323.00	6.15	0.74	8,690.61	44.30	51.69	58.3	27.89	45.18	576	0.59	55.3	104
Serifos	1,378	76.17	0.12	2.32	0.20	−1.06	623.73	34.48	74.03	75.9	21.59	42.03	11	0.10	53.4	72
Sifnos	2,543	78.33	0.39	29.88	0.88	−0.19	969.50	29.86	63.10	67.1	19.50	54.21	87	0.19	63.5	124
Sikinos	270	43.27	0.08	2.08	0.24	−0.96	163.92	26.27	66.77	68.6	33.49	34.42	16	0.03	75.6	141
Simi	3,070	65.30	0.18	6.08	0.37	−0.83	1,229.20	26.14	55.12	53.5	13.82	18.67	31	0.12	67.5	131
Syros	21,475	102.37	1.14	116.08	2.25	0.19	1,186.15	5.65	35.75	44.4	30.90	91.41	322	1.06	56.4	139
Tilos	829	63.36	0.03	1.16	0.07	−0.81	no data	no data	63.76	54.6	43.70	75.79	16	0.01	90.0	333
Tinos	8,699	196.99	1.21	100.76	1.13	−0.09	1,625.48	36.81	76.01	65.6	31.95	289.39	445	0.49	70.4	198
Chalki	702	36.15	0.04	0.32	0.14	−1.23	96.12	4.95	74.69	71.9	9.26	66.78	4	0.02	91.2	80
Chios	51,269	844.67	6.19	379.56	1.18	−0.41	128.59	2.12	48.83	45.8	19.37	6.63	1,050	1.40	56.0	105
N	43	43	43	43	43	43	40	40	43	43	43	43	43	43	43	43
Mean	13,155.7	213.1	1.32	118	1.14	.00	892.22	18.63	55.3	48.4	25.2	55.33	262.14	.39	61.4	127.9
Median	2,480.0	90.5	0.30	20	0.77	–.31	435.24	13.48	55.9	50.7	24.8	46.30	82.00	.14	61.6	124.0
Std. Deviation	27,446.1	338.7	2.20	218	1.87	.999	1567.1	14.0	11.11	14.3	10.4	57.04	404.0	.56	13.3	68.5

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these locations. Fear of pirates began in the sixth century and lasted to as late as the early nineteenth century, leading to a few fortified and very compact settlements on the coasts of most of the bigger islands. For the same reason, settlements were also located on slopes, at safe distances from the coast and either in places where the sea could be watched, or in locations which were not visible from the sea. Even these settlements tended to be compact with clear boundaries and very small spaces between buildings and public spaces, again for reasons of defence. Another reason for not settling along the coasts was that in many of them, periodic flooding and wetlands made living conditions unsanitary. Depending on the size of the island, smaller settlements other than the main port were created, but again these were compact.

Coastalisation began in the twentieth century and became a strong trend after the 1950s, coinciding with population losses and the growth of the bigger settlements, namely cities, on the islands. For example, on Lesvos the population of the island decreased by 35 per cent between 1951 and 1991, but the population of the capital Mytilini tripled in the same period (Kizos & Koulouri 2006). Therefore, there are three processes that drive building expansion:

1. New settlements in coastal areas where there was no settlement in the past, only a few houses or huts to serve the rising tourism development. This process is typically unplanned and random, resulting in less compact and very diverse settlements.
2. Expansion around older small coastal settlements: this typically expands the limits of the old settlement, with new buildings in the countryside in former fields and along the road network, or in scenic locations with views.
3. Expansion of 'capital' settlements on bigger and medium size islands, which take up all neighbouring areas and facilitates new residents, but also tourism to a lower or higher degree.

There are three developments leading to an increased number of buildings, either inside or outside settlements: (i) first homes: houses for the permanent residents of the islands; (ii) second homes: houses that can be for non-permanent residents who come to the islands for vacation, or for permanent residents. The non-permanent residents may be domestic or foreign, including former out-migrants that left the island in the past, who build or renovate a house, or complete newcomers. The houses may also be for permanent residents that keep a family house or buy a holiday house on bigger islands; (iii) tourism facilities.

Typical architectural styles differ across the archipelago following historical developments and availability of building materials, especially timber for rooftops. In the smaller and drier islands, buildings tend to be small, with small rooms and a few windows that look to the south. Yards and outside spaces are also small and in many instances integrated with public spaces, which are also small and narrow. The exception is the church yard with a nearby square, which is the centre of social life. On bigger islands styles differ, but the structure of the settlements is similar. As many as 307 settlements are designated as 'traditional' by the national building legislation (Tsilimigkas *et al.* 2015). New buildings within the designated settlement area are almost prohibited and renovations have to respect very strict rules pertaining to the building's exterior and the structure of the settlement. Some of these rules (regulated by Law 3201/2003) concern the morphology of the building and the settlement tissue. This includes matching the construction with the 'scale' of the settlement, local topography, 'key views' in public areas, and landmarks. It is also necessary to preserve or restore traditional structures of the settlement and the immediate landscape (e.g. paths, stonewalls, etc.). Local architectural character must also be taken into account, which sometimes presents differences within each island, and ensures 'authenticity'. This architectural character includes building forms, proportions, allowable colours, balconies, and windows and doors, among others. Special attention is paid to incorporating new materials such as reinforced concrete and modern equipment such as air conditioners, solar panels, electricity meters, etc. Although these regulations are very strict and almost

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restrictive at times, the hard reality is that in many cases these rules have been followed only partially or not at all, since policing and especially penalising is problematic.

Tourism development has occurred very unequally across the islands. Big islands such as Rodos (Rhodes) were tourism destinations as early as the 1930s (then still part of the Italian State). Others were 'discovered' in the 1960s and 1970s (e.g. Mykonos and Santorini), still more became tourism destinations in the 1980s, and some smaller islands are still reported in tourism guides as 'undiscovered' by tourism. The timing of mass tourism is important, and of course so is the existence of a local airport, but mass tourism development has developed under the influence of other factors than time of discovery. For example, Kos became a mass tourism destination relatively late (in the 1980s), but it has since become one of the highest tourism density islands. Finally, building regulations for hotel size favoured smaller and scattered buildings and/or separate small houses, with the exceptions of Rodos and a few notable examples of hotels around the Aegean.

Indicators used – The spatial indicators used for built-up area are: the soil sealing cover (Table 1), in which higher percentage values imply higher coverage from impenetrable materials. This coverage is considered to be an indication of man-made pressure (European Commission 2012) and built-up area. The indicator represents the percentage of both sealed cells (1–79% of total area covered by impenetrable material) and built-up areas (80–100% of total area covered by impenetrable material) of the total land area of the island.

Compactness, which represents the ratio of built-up areas per sealed cells area. Here higher values mean more compact settlements. The values have been standardised according to the following formula (1):

$$\text{Standardised value} = (\text{value} - \text{mean})/\text{standard deviation} \quad (1)$$

Number of patches (NumP), which is a simple composition index of the number of separate patches of built up area on each island and provides an initial overview of the extent of subdivision or fragmentation of the patch type (McGarigal *et al.* 2012).

Greatest patch area (GrPA), which is a patch-based metric that provides a simple measurement of sealed soil patch size. In our case, it highlights continuous soil sealed areas in the studied islands. High values typically mean higher levels of homogeneity and lower levels of patch dispersion for the specific land cover class.

Edge density (ED), which is a shape configuration metric measuring the morphological complexity of the sealed soil patch patterns. It reports the edge length on a per unit area basis that facilitates comparison among landscapes of varying size (Jung 2012; McGarigal *et al.* 2012). It is calculated with the following formula (2):

$$ED = E/A, \quad (2)$$

where (E) stands for total edge length (in km) and (A) stands for total landscape area (in km^2)

Patch density (PD), which is a spatial aggregation index, defined as the ratio between the number of patches of a land cover class to the total area (Jung 2012). It is an index of the spatial distribution of the patches of a land cover class (Prastacos *et al.* 2012). It displays landscape homogeneity or, conversely, heterogeneity that can be expressed by the number of patches of each class, facilitating comparisons among landscapes of varying size (McGarigal *et al.* 2012). High values represent more fragmented land cover classes (here sealed soil) which implies higher spatial heterogeneity. It is calculated with the following formula (3):

$$PD = n_i/A, \quad (3)$$

where (n_i) stands for the number of patches of a land cover and (A) stands for the total landscape area (in km^2)

The socio-economic indicators used are: population, which expresses the permanent population of the island. Islands were grouped in four classes: small islands with population less than 1,000 inhabitants (12 islands), small to medium size islands with population between 1,000 and 10,000

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inhabitants (19 islands), bigger islands with population between 10,000–100,000 (11 islands), and islands with more than 100,000 people (only the island of Rodos).

Tourist density, which expresses the pressure of tourism arrivals on the islands and the level of tourism development. The main difficulties concern the proper identification of who the 'tourist' is (Baldacchino & Ferreira 2013). First, not all passengers on flights and ferries are tourists: many are local residents. The available data are the total number of arrivals by airplanes and ferries on each island, which includes residents travelling as well. We assume that the number of arrivals in February reflects the travels of residents and we also assume that residents travel with the same frequency throughout the year, so the total number of February arrivals is multiplied by 12 and subtracted from the total annual number of arrivals to provide the number of tourism arrivals (Karampela *et al.* 2015). The first indicator is tourist arrivals/km^2 of the island, which provides an indication of the level of tourism development and pressure regardless of size. The second indicator is tourist arrivals/population of the island, which provides an estimation of the social pressures of tourism development (Coccosis 2002; McElroy 2003). For tourism arrivals/km^2, five classes were created, one with 5 islands of very low pressure (<100 tourists/km^2), one with 19 islands of low to medium pressure (100–500 tourists/km^2), one with seven islands of medium pressure (500–1,000 tourists/km^2), one with six islands of high pressure (1,000–3,000 tourists/km^2) and one with 3 islands of very high pressure (>3,000 tourists/km^2, these being the islands of Kos, Mykonos and Santorini).

The ratio of empty houses to the total number of houses of each island, which expresses the stock of empty houses on the islands. Empty houses can be empty for three reasons: (i) they are tourism buildings (rooms to let, hotels, etc.) which are empty during March when the census takes place; (ii) they are second homes for part time residents of the island, again typically empty during March; or (iii) they are closed houses of people that do not live on the island any more. Two indicators are used, one for 1991 and one for 2011. For empty houses percentage of total houses in 2011, four classes were constructed, one with 11 islands with less than 48 per cent of their houses being empty, one with 9 islands with 48 and 56 per cent of the total number of their houses being empty, one with 13 islands with 56–65 per cent and one of 10 islands with more than 65 per cent of their houses being empty.

The change of empty houses between 1991 and 2011, which indicates if more houses have been left empty in the last 20 years. The reasons for an increase of the number of empty houses can be related to either of the three categories of empty houses, typically with second homes first, tourism facilities second and closed houses last.

The number of houses built after 1991 as a percentage of the 2011 number of houses, which expresses the amount of relatively new houses (built in the last 20 years or so) in the current housing stock.

Data sources – The soil sealing geospatial datasets used were produced as part of the Global Monitoring for Environment and Security (GMES) as a Fast Track Service on Land Monitoring in 2006–2008. Soil sealing is the first high-resolution Land monitoring layer provided by the EEA with European coverage (Maucha *et al.* 2010). The soil sealing layer contains continuous values ranging from 0–100 per cent of cover representing different degrees of soil sealing. Sealed cells represent impervious surfaces from artificial structures '...such as pavements, roads, sidewalks, driveways, parking etc. lots that are covered by impenetrable materials such as asphalt, concrete, brick, and stone and rooftops' (Maucha *et al.* 2010). The degree of soil sealing or imperviousness is estimated in relation to the pixel area cover. Built-up areas are impervious, artificially covered surfaces that account for 80 to 100 per cent of the total cover.

The spatial structure of the data is raster and they are provided in Lambert azimuthal equal area (LAEA) coordinate reference system. A useful property of this projection is that it does not distort areas; therefore a comparative analysis in greater scale is possible. The spatial resolution of the data-set is 100 ×

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100 m and 20 × 20m (Kopecky & Kahabka 2009).

Soil sealing data was validated in the 'European validation of GMES Fast Track Service on Land Monitoring Soil Sealing Enhancement data' report (Maucha *et al.* 2010). The main findings of the validation of the built-up class (80%) reveal significant commission error (i.e. some non-built-up samples were erroneously classified as built-up) and low calculated omission error (i.e. few built-up samples were classified as non-built-up). The data is provided for 38 countries (EU 27 and neighbouring countries) (Kopecky & Kahabka 2009), allowing international comparisons.

For socio-economic variables, the data for population and number of houses, including the number of empty houses, come from the population and housing censuses of 1991 and 2011, available from the Hellenic Statistical Authority (EL.STAT.). The calculation of tourist arrivals by air and sea was based on annual statistics data of disembarked passengers for 2011, obtained from the Civil Aviation Authority and the Hellenic Statistical Authority respectively.

RESULTS

Results for socio-economic indicators – The increase in the total housing stock in the last decades (1991–2011) is very important (the median is 38%). There are only two islands where the numbers suggest decrease (Psara at −20% and Oinousses at −3.8%), which – if not a mis-measurement by the last census – can be attributed to the significant population losses on these islands in the previous decades, which may have rendered many of the empty houses in previous decades uninhabitable. These houses would therefore not be recorded by the census. The rest of the percentages range from modest percentages on bigger islands, such as 13 per cent on Chios and 15 per cent on Lesvos, to 350 per cent on Tinos, 128 per cent on Antiparos and 114 per cent on Mykonos. The high increase rates on smaller islands may represent few absolute numbers of houses in total, but are important for these small islands. The increase rate is not correlated to population size, as bigger and smaller islands have increased their stock by varying degrees. Although the values are also not correlated in a statistically significant way to tourism density, the increase rate is higher with tourism density classes, from 34 per cent in the lowest class (less than 100 arrivals/km^2) to 88.5 per cent in the 1000–3000 arrivals/km^2 class. However, the rate decreases to 73.6 per cent in the highest class (more than 3000 arrivals/km^2).

Another way of looking at this increase in housing stock is to examine the percentage of the newly built houses of the total housing stock. Here, with a median value of 24.8 per cent, there are important differences between the islands. On some small and very small islands the rates are lower (e.g. 7.6% on Kasos and 9.2% on Chalki) suggesting extensive renovation of older buildings, which has to be carried out according to local building styles, as both settlements are designated as 'traditional' and protected. On others, the rates are very high, with 55 per cent of the total housing stock being built after 1991 on Antiparos, a small island close to Paros; almost 50 per cent on Kea, the island closest to metropolitan Athens area; 43 per cent on Tilos; and 42 per cent on Mykonos (see Table 2). The rates are related to tourism density (Table 3), as the average value of this indicator per tourism density class increases from 14.4 per cent on islands with less than 100 arrivals/km^2 to 33.7 per cent on islands with more than 3000 arrivals/km^2. The differences are statistically significant (ANOVA $p < 0.05$). On the contrary, no such differences are recorded for the empty houses to the total housing stock percentages classes.

The number of new houses built between 1991 and 2011 is very strongly correlated to the change in number of empty houses during the same period (Pearson's Rho = 0.91, $p < 0.001$, $N = 43$), which seems to suggest that some of these new houses will be empty during the time of the census (March). At the same time, the percentage of empty houses to the total housing stock are not correlated.

Results for spatial indicators – The results for soil sealing reveal relatively low values for

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Table 2. *Average values for spatial and socioeconomic indicator for population classes*

Population classes	Sealed cells (km^2)	Build–up (km^2)	Island soil sealing (%)	Tourist density (tourist arrivals/km^2)	Compactness (Standardized Value)	Empty houses/km^2 in 2011	Number of houses built after 1991 percentage of 2011 houses	Empty houses change 1991–2011%
<1000 inh. (N = 12)	0.067	0.052	0.46	288.86	0.27	10.92	0.24	0.38
1000 – 10000 inh. (N = 19)	0.468	0.336	0.60	600.61	−0.25	19.04	0.24	0.69
10000 – 100000 inh. (N = 11)	3.397	3.257	2.76	1,901.39	0.15	36.75	0.28	0.51
>100000 inh. (N = 1)	9.601	8.276	1.27	1,385.91	−0.04	15.59	0.28	0.52
Total (N = 43)	1.318	1.188	1.13	892.22	0.00	21.22	0.25	0.55

Table 3. *Average values for spatial and socioeconomic indicator for tourism density classes*

Tourism density (arrivals/km^2) classes	Island soil sealing (%)	Compactness (Standardized Value)	Tourist density (tourist arrivals/pop.)	Empty houses/km^2 2011	Empty houses 2011/ Total houses (%)	Number of houses built after 1991/ 2011 houses (%)	Empty houses change 1991–2011 (%)
100 tourists/km^2 (N = 5)	.51	0.169	5.94	12.7	55.8	14.4	42.1
100 – 500 tourists/km^2 (N = 19)	.73	−0.079	14.04	16.2	54.8	24.5	43.2
500 – 1000 tourists/km^2 (N = 7)	.58	−0.564	29.41	20.1	60.7	23.2	46.4
1000 – 3000 tourists/km^2 (N = 6)	1.16	0.040	23.46	31.8	52.5	29.2	80.5
> 3000 tourists/km^2 (N = 3)	6.56	0.865	34.11	55.1	50.2	33.7	86.3
Total (N = 40)	1.18	−0.044	18.63	21.7	55.3	24.4	52.5

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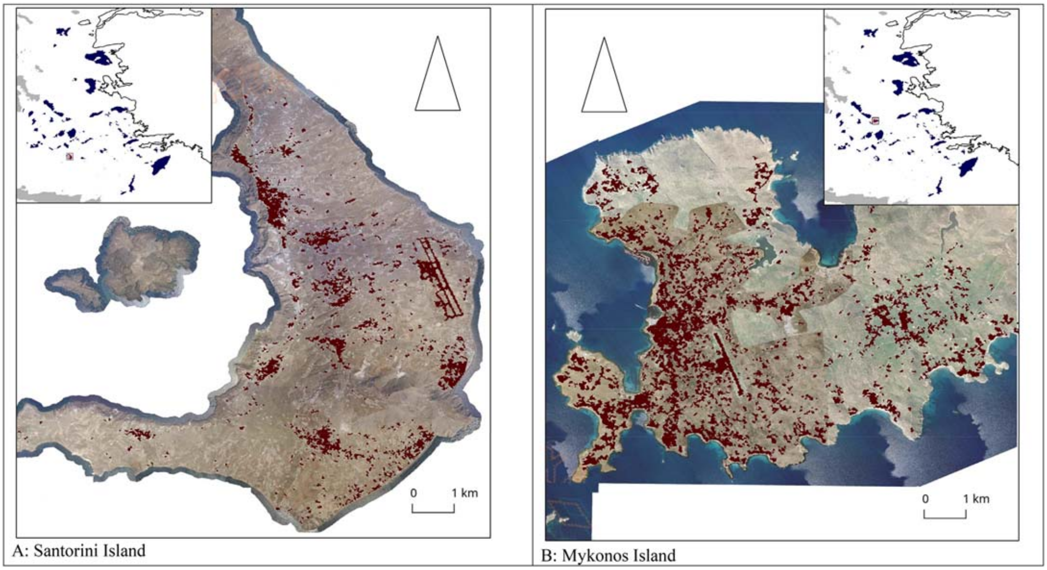

Figure 2. *Soil sealing of (a) Santorini and (b) Mykonos, Cyclades. [Colour figure can be viewed at wileyonlinelibrary.com]*

most of the islands, with few notable exceptions. With an average value of 1.1 per cent and a median of 0.7 per cent, there are some extreme values, namely Mykonos with 11.2 per cent and Santorini with 6.2 per cent (see Figure 2), while Kos and Syros have values higher than 2 per cent (Table 1). Mykonos, Santorini and Kos are three of the most important tourism destinations of Greece and therefore it is unsurprising that the values of soil sealing are correlated to tourism density as expressed by tourism arrivals/km^2 (Pearson's Rho= 0.79, $p < 0.001$, $N = 43$). The values are not correlated to population, but a closer examination of the soil sealing values for the population classes reveals that the average value for the smallest islands (<1,000 inhabitants) is only 0.46 per cent, while it is 0.6 per cent for the small to medium size islands (1,000–10,000 inhabitants) and increases rapidly for bigger islands (2.76% for 10,000 to 100,000 inhabitants), as all islands with high values of soil sealing percentages are in this population class. The average differences between the population groups (Table 2) are statistically significant with $p < 0.005$.

The number of houses per island is not correlated to soil sealing percentages, and neither is the number of empty houses per island. This can be explained, as the percentage of empty houses of the total houses in each island is inversely related to the population. Smaller populations present higher percentages of empty houses per total houses compared to bigger islands (Table 2): 53.4 per cent for islands with less than 1,000 inhabitants and 61.8 per cent for islands with 1,000–10,000 inhabitants, compared to 49.8 per cent for islands with 10,000–100,000 inhabitants and 34.2 per cent for bigger islands. These differences are statistically significant ($p < 0.01$). Soil sealing values do not seem to follow this distribution, probably due to tourism. Therefore, averages of soil sealing percentages are higher (1.9%) for islands with high degree of empty houses (between 56 and 65%), but are lower (0.5%) for islands with the highest percentage of empty houses (more than 65%), which are some of the smallest islands of the Aegean. Islands with low percentages of empty houses (<48%) are bigger islands and have relatively high percentage of soil sealing (1.1%), while the average for the class 48–56 per cent is again low (0.6%).

For compactness, the values of the indicator are not correlated to socio-economic

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Table 4. *Pearson Correlation matrix*

	Population 2011	Surface (km^2)	Island soil sealing (%)	Island Population density (P/km^2)	Tourist arrivals/km^2	Compactness	Tourist arrivals/pop.	Total houses 2011	Empty houses 2011	Empty houses/km^2 2011	Empty houses/Total houses 2011	Houses built after 1991% of houses 2011	Empty houses/Total houses 1991	Empty houses/Total houses 2001	Empty houses change 1991–2011%	Number of patches	Greatest patch area (km^2)	Edge density (km)	Patch density ($1/km^2$)	Houses change 1991–2011%
Population 2011 (N = 43)	1	0.9***	0.14	0.4***	0.13	−0.03	−0.23	0.95***	0.87***	0.1	−0.43	0.02***	−0.5***	−0.39***	−0.06	0.93***	0.75***	−0.14	−0.11	−0.07
Surface (km^2) (N = 43)		1	0.02	0.17	−0.05	−0.06	−0.29	0.96***	0.95***	−0.04	−0.31**	−0.04	−0.37**	−0.28	−0.11	0.82	0.75***	−0.19	−0.14	−0.12
Island soil sealing (%) (N = 43)			1	0.64***	0.79***	0.36**	0.23	0.16	0.19	0.68***	−0.05	0.3	−0.21	−0.04	0.27	0.36**	0.57***	−0.18	−0.15	0.16
Island Population density (P/km^2) (N = 43)				1	0.67***	0.09	−0.08	0.39	0.38**	0.82***	−0.36**	0.16	−0.54***	−0.36**	0.13	0.52***	0.51***	−0.05	0.02	0.04
Tourist arrivals/km^2 (N = 40)					1	0.24	0.47***	0.11	0.14	0.76	0	0.32**	−0.11	0.01	0.21	0.32**	0.3	−0.06	−0.01	0.17**
Compactness (N = 43)						1	0.1	−0.04	−0.03	0.12	−0.11	0.17	−0.05	−0.17	0.14	0.02	0.19	−0.59***	−0.4***	0.15
Tourist arrivals/pop. (N = 43)							1	−0.27	−0.25	0.14	0.31	0.32**	0.45***	0.5***	0.11	−0.13	−0.16	0.08	0.1	0.23
Total houses 2011 (N = 43)								1	0.98***	0.17	−0.38**	0.01	−0.45	−0.34**	−0.06	0.9***	0.81***	−0.18	−0.13	−0.08
Empty houses 2011 (N = 43)									1	0.23	−0.29	0.03	−0.38**	−0.27	−0.03	0.85***	0.81***	−0.19	−0.13	−0.05
Empty houses/km^2 2011 (N = 43)										1	0.09	0.25	−0.14	−0.03	0.31**	0.26	0.35**	−0.04	0.02	0.19
Empty houses/Total houses 2011 (N = 43)											1	0.15	0.73***	0.59***	0.37**	−0.38**	−0.3**	0.14	−0.01	0.23
Houses built after 1991% of houses 2011 (N = 43)												1	0.08	0.03	0.42***	0.16	0.1	0.29	0.46***	0.4***
Empty houses/Total houses 1991 (N = 43)													1	0.63***	0.09	−0.45***	−0.45***	0.2	0	0.25
Empty houses/Total houses 2001 (N = 43)														1	−0.05	−0.34**	−0.25	0.11	−0.04	−0.03
Empty houses change 1991–2011% (N = 43)															1	0.04	0.11	0.15	0.22	0.91***
Number of patches (N = 43)																1	0.79***	−0.08	−0.02	0.04
Greatest patch area (km^2) (N = 43)																	1	−0.34**	−0.29	0.03
Edge density (km) (N = 43)																		1	0.83	0.21
Patch density($1/km^2$) (N = 43)																			1	0.26

***Correlation significant at the 0.001 level,

**Correlation significant at the 0.05 level

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indicators (population, tourism density or the percentage of empty houses). Compactness is weakly correlated to soil sealing (Pearson's Rho $= 0.36$, $p < 0.05$, $N = 43$). Islands with the highest values are typically small or very small islands, for example, Megisti (2.60 of 11.71 km^2, with 496 inhabitants, high soil sealing rate of 1.3%, very low tourism density at 6.5 arrivals/km^2 and high percentage of empty houses at 62.8% of total houses, while it is also one of the most remote islands geographically), and Agios Efstratios (2.59 of 42.10 km^2, with 249 inhabitants, very low soil sealing rate of 0.24%, very low tourism density at 10.3 arrivals/km^2 and medium percentage of empty houses at 56.6% of total houses). Both islands have only one central and compact settlement where all of the population resides. Following Megisti and Agios Efstratios, the third highest value of compactness is for Mykonos (2.20), which is bigger in size than the other two, with very high tourism density and extended settlement sprawl (Salvati 2013). It would seem that this excessive sprawl is detected in compact settlements precisely because of its extent. The lowest values are found on small and very small islands such as Chalki (−1.23), Serifos (−1.06) and Kithnos (−1.03), which are characterised by the existence of one central settlement (typically where the port is also located) and many smaller settlements scattered around the island. It would therefore seem that historical factors related to settlement development in the past 1–2 centuries determine compactness to an extent, with the exception of islands where tourism development in the last decades has altered historical developments.

The rest of the spatial indicators seem to support these findings. For the number of patches (the composition index), the values are correlated very strongly and positively with population (Pearson's Rho $= 0.93$, $p < 0.001$, $N = 43$). Therefore, the highest values are found on the biggest islands, such as Rodos (2.03), Lesvos (1.04) and Chios (1.05), with important and compact urban centres where more than 50 per cent of the total population of the island resides. The lowest values are found on small and very small islands with less than 10 patches per island, and as few as two patches in Agios Efstratios and three in Psarra.

The greatest patch area (the spatial configuration index), is strongly correlated to the number of patches and to population (Pearson's Rho $= 0.79$, $p < 0.001$, $N = 43$ and Pearson's Rho $= 0.75$, $s = 0.000$, $N = 43$, respectively, Table 4). Therefore, some of the highest values are again found on the biggest islands (Lesvos, Rodos, Chios). Exceptions to this are islands such as Mykonos, on which the highest value is found (2.1 km^2), due to the excessive urban sprawl (this patch covers roughly 2 per cent of the total island area). The lowest values are again found on small and very small islands like Agathonisi (0.009 km^2), Tilos (0.01 km^2) and Chalki (0.03 km^2).

Edge density (the shape complexity index) is not correlated to population or any of the other indicators related to soil sealing (tourism density, empty houses, Table 4), but is negatively and weakly correlated to the greatest patch area and compactness (Pearson's Rho $= -0.34$, $p < 0.05$, $N = 43$ and Pearson's Rho $= -0.59$, $p < 0.001$, $N = 43$, respectively). Therefore, the highest values for edge density are found on some of the islands with less compact sealed areas, like Chalki, Tilos and Lipsi, while the lowest values are on islands with high compactness values, such as Megisti and Agios Efstratios. Here, again, the historical development of settlements on the islands seems to be of importance.

For patch density (the aggregation index), the values are strongly correlated to those of edge density (Pearson's Rho $= 0.83$, $p < 0.001$, $N = 43$) and therefore they are also correlated negatively with compactness (Pearson's Rho $= -0.4$, $p < 0.001$, $N = 43$). They are not correlated to socio-economic indicators such as population, tourism density or empty houses. The highest values for patch density are again found on small islands such as Tilos (333) and Agathonisi (230). High values are also found on bigger islands such as Andros (225) and Paros (223), on which also tourism density is also high and many settlements are found, leading to higher spatial heterogeneity in soil sealing patterns. The lowest values are in compact, single settlement and small islands such as Psara (18),

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Agios Efstratios (20) and Megisti (38), as well as on Limnos (47), which is characterised by a very low population density (35 inh./km^2). The low value for Mykonos (61) is explained by the large number of patches and the very high percentage of total cover of the island by sealed cells, demonstrating again the severe stress caused by built-up forces.

DISCUSSION

The short historical sketch in the previous section, outlining the changes of settlements and urban sprawl in the Aegean Islands, explains a number of developments in the findings. First, urban sprawl makes sense in this context for a number of reasons: it is much more difficult and expensive to build or renovate a building inside the compact older settlement, which ultimately will remain a small house inside a packed and crowded settlement, than building outside the settlement, which can be more spacious and adapted to modern expectations of a house and its functions. At the same time, a house outside the older settlement provides more exterior space, for example for verandas, balconies, pools, parking, etc., as well as other facilities that second home owners and tourists seek. Moreover, land is more affordable outside the settlements. Finally, if building takes place on (former) agricultural land, it is easier to get a building permit than inside an already-existing settlement. This is a difference from other island cases where sprawl can take place more systematically with blocks of second homes or tourism developments (see Pons *et al.* 2014; Hall 2015; Walters & Duncan 2014). Therefore, a number of findings such as the weak correlation of compactness and soil sealing can be explained by the particular regulations of building inside and outside of the settlements.

Second, the existence of compact single settlements in some of the smaller islands explains the high values of compactness and low levels of soil sealing, as well as the increase in number of houses shown in the censuses, as most of these newer houses are built around the settlements or replace older and derelict buildings. Building in this way is a trend among a particular category of second home owners, namely, people who emigrated from the islands some decades ago and return to rebuild/renovate their old family house, or the offspring of these emigrants. On smaller, 'satellite' islands (which depend on nearby, bigger islands for services, Karampela *et al.* 2015), this trend is especially prevalent, as many migrants chose to live on the bigger island nearby instead of moving to continental Greece or abroad.

Third, the inequality of tourism development has generated very important differences in the demand for buildings. Given that building on Aegean islands is more expensive than in continental areas, and that land and houses on some popular islands are very expensive (land value prices for tax purposes on Mykonos and Santorini are the highest in Greece and comparable only to the centre of Athens), it is no surprise that people who can afford a second home on some of the most expensive islands expect luxurious homes (Salvati 2013).

Fourth, the values of spatial indicators have limited variation among the study islands, partially due to similar geographical characteristics (relief, few level areas etc.) that favour complex urban morphologies, but also because of similarities in the islands' settlement histories. Despite the general lack of variation, some exceptional cases differ significantly.

Three idealised types of islands seem to emerge. The first type is tourism islands, where high tourism density leads to higher percentages of built-up areas, as high soil sealing values seem to imply, as well as more sprawl and less compact settlements. Islands such as Mykonos, Santorini and Kos are extreme cases of this group. Another type seems to be 'second home islands', where tourism density is lower, but the percentage of empty houses is high, with lower (but not always low) percentages of built-up areas, and less sprawl. Bigger islands such as Lesvos and Chios are found here, along with islands closer to Athens, such as Kea, and popular islands for tourists such as Antiparos. The third type is 'less developed islands' that do not fall within any of these categories and are typically smaller, with low tourism densities,

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lower values of buildings increase, a few (or one) compact settlements, and low percentages of built-up areas. Agios Efstratios, Chalki, Kasos are typical examples.

The delimitations between these types are not always clear and although some islands can be placed into discrete categories, many islands fall somewhere along a continuous spectrum, especially smaller and not very popular islands. From a planning and management perspective, these types represent ideal cases, to assist local or regional administration to manage flows and processes. The islands appear to be part of a system in which, although very strict planning rules have been set (especially in building form and location), the final outcome often resembles non-regulated areas where market forces, tourism, and second homes have dominated completely and have driven built-up area expansion.

According to urban planners in Greece (Economou 2004; Karidis 2006), one of the reasons for the overall ineffectiveness in harnessing urban sprawl is exactly this very strict framework for existing traditional settlements, combined with a much 'looser' spatial planning framework. This allows houses to be built on agricultural land and has many 'loopholes' and exceptions, while also lacking detailed land-use planning schemes (see Tsilimigkas & Kizos 2014 for a discussion). The result is the domination of spontaneous, self-promoted housing strategies in and around settlements.

PLANNING PERSPECTIVES: CONCLUSION

In this paper, we used spatial and socio-economic indicators to examine the expansion of built-up area, its extent, and its patterns (shape complexity and aggregation). The case study of 43 islands of various sizes, remoteness and levels of economic development has shown that in many different cases, similar driving forces and pressures (tourism and/or second homes) have prevailed. The national planning and management context is the same across all cases, and this paper provides a useful overall assessment of its effectiveness with a combination of spatial and non-spatial data. The findings seem to confirm that 'unleashing' tourism without a spatial planning framework and monitoring almost certainly leads to the rapid development of buildings, in order to satisfy the growing demand by tourists and second home seekers. In Greece, and in the islands in particular, urban areas developed principally by spontaneous, self-promoted housing strategies, driven by market dynamics. These ad-hoc procedures exploited loopholes and/or only partial application of the spatial planning framework and the very strict building regulations. Such exploitation was encouraged by the overall institutional and political system.

The spatial indicators related to soil sealing are available throughout Europe, allowing comparisons, while their spatial scale can help make quantitative estimations even in the case of smaller islands and in situations with many dispersed buildings around and outside settlements, with often indiscernible boundaries between housing and other areas. The fact that in this particular case study socio-economic indicators for constructions and population are available only at 10 year intervals, and economic indicators available only at NUTS 3 level, makes the use of spatial indicators even more useful, as they provide not only the extent of built-up area, but also spatial metrics of the plots. These findings are subject to spatial data format and availability, the scale, and the method employed for acquiring data for urban areas, and the metrics used. The format we used was raster and not vector for the calculation of the metrics, as even if 'edge lengths will be biased upward in a raster' according to McGarigal (2002), any distortions were similar for all islands. The scale used was 1/20,000, considered suitable to capture the spatial heterogeneity of the built-up areas and to quantify the differences of compactness and geometric shape (Stathakis & Tsilimigkas 2014) common for physical planning (Tsilimigkas *et al.* 2016). An approach at other scales could offer more geometric details, especially in cases of smaller buildings outside the settlements, but could not be used in comparisons

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with other insular areas in Europe or other localities in Greece.

To conclude, from a planning perspective, the approach employed in this paper can provide a link between different driving forces and the expansion of built-up areas. This largely quantitative approach provides the overall framework for describing and understanding the changes in relation to the different driving forces and the islands' histories, but requires the input of qualitative data, especially in relation with the different trajectories of different islands. For instance, more in-depth research on some of the islands that emerged as exceptional cases from the exploration of this paper could be conducted. This would provide more insights into how the driving forces described here are realised in terms of actual built-up area expansion (Who is building? How? Who is buying the buildings? For how long are these buildings used? By whom?), as well as the effects of these developments on local economies and societies.

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