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Analyzing land cover change dynamism through a GIS-based method: application to Gran Canaria (Canary Islands, Spain)

Analizando la dinámica de cambios en las coberturas del suelo a través de un método con SIG: aplicación a Gran Canaria (Islas Canarias, España)

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Abstract

Landscapes are dynamic areas which can be studied from the perspective of different, but related, disciplines. The application of GIS methods to study landscape change is an interesting resource to help understand and explain landscape dynamics. Thus, the objective of this paper is to characterize land cover dynamism and identify land cover change 'hotspots'. The method used here generates raster maps in which each pixel value represents the number of times each pixel has changed land cover between 1990-2018. Furthermore, it provides three of these maps, since it works with the 3 taxonomic levels of Corine Land Cover datasets, giving us different levels of detail in the analysis. On the other hand, the statistical treatment of the data has been done at the municipal level. The most important results reveal that Agüimes is the municipality with the most dynamic land cover change in the three levels, while Tejeda, in level 1, and Valsequillo, in levels 2 and 3, have the least changing land cover. These outputs are complemented with other statistical analyses which allow the integration of different data types such as those related to population, tourism and agriculture. Subsequently, some of the methodological issues and findings are discussed and put in context with the scientific literature.

Keywords: spatial analysis; land cover dynamism; land cover change; Corine Land Cover; Gran Canaria.

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Resumen

Los paisajes son áreas dinámicas que pueden ser estudiadas desde la perspectiva de diferentes disciplinas relacionadas. La aplicación de métodos con sistemas de información geográfica para estudiar cambios en el paisaje es un recurso que ayuda a entender y explicar la dinámica del paisaje. Así, el objetivo de este artículo es caracterizar el dinamismo de las coberturas del suelo y la identificación de los 'hotspots' (puntos calientes) en los cambios de las mismas. El método utilizado aquí genera mapas ráster en los que el valor de cada píxel representa el número de veces que cada uno de ellos ha cambiado de cobertura entre 1990 y 2018. Además, este método proporciona tres mapas, ya que trabaja con los tres niveles taxonómicos de los datos del Corine Land Cover, dándonos diferentes niveles de detalle en el análisis. Por otro lado, el tratamiento estadístico de los datos se ha hecho a nivel de municipio. Los resultados más importantes revelan que Agüimes es el municipio con los cambios de cobertura del suelo más dinámicos en los tres niveles, mientras que Tejeda, en el nivel 1, y Valsequillo, en los niveles 2 y 3, tienen las coberturas de suelo menos cambiantes. Estos resultados son complementados con otros análisis estadísticos que permiten la integración de diferentes tipos de datos, como son los relativos a la población, al turismo y a la agricultura. Seguidamente, algunos problemas metodológicos y resultados son discutidos y puestos en contexto con la literatura científica.

Palabras clave: análisis espacial; dinámica de las coberturas del suelo; cambio de las coberturas del suelo; Corine Land Cover; Gran Canaria.

1. Introduction

Landscapes are dynamic areas which evolve as the result of human and/or natural factors, although most of the time they act in combination (Antrop, 1998). Their dynamism triggers changes that can be quantified and explained, although this is by no means an easy task. In this respect, some important contributions have been made from the perspective of landscape ecology through the study of landscape patterns and metrics (Gustafson, 1998; Turner, 1990), basic issues in this discipline. Their objective is to characterize the land units and study their distribution in a given moment as well as their effects on landscape processes (Turner, 1989). On the other hand, several challenges and methodological issues have also been identified and described in land change science (Rindfuss et al., 2004; Turner et al., 2007), which has emerged in response to global environmental change. This discipline is based especially on land use and land cover changes from global to local scale, and methodological issues related to it are continuously addressed. Some of these issues are tackled using geographical information systems (GIS) and remote sensing. For its part, historical ecology has provided researchers with a framework through which to study past landscapes and understand their current processes and patterns. Thus, diachronic landscape studies ranging from decades to centuries can now be approached from a solid background of varying perspectives which can potentially be integrated for better results and comprehension of what are often complex issues in terms of human-nature interaction. It should be noted that, at theoretical level, integration questions in relation to ecology and history, or science and humanities, have been highlighted as a key element in historical ecological studies (Crumley, 1994; Szabó, 2010). Their integration constitutes a clear advance in the successful undertaking of landscape-scale case studies.

Focusing now on spatio-temporal land changes, these are globally present, with human intervention not necessary for their occurrence given the continuous dynamics of natural processes. In this regard, the concepts of change and persistence are very important, and theoretical and practical advances associated with them have become an essential resource for researchers studying landscape dynamics (Bürgi et al., 2015; Lieskovský and Bürgi, 2018). Beyond the obvious statement that land is continuously changing, it should be noted that the change will depend on the time scale and the human activities carried out in the land under study, as the latter can provoke persistence by maintaining, for example, the same land cover through the years. However, we have to consider that a plot of land can be continuously changing, thus introducing the question of the frequency of change, as argued by Antrop (1998). It can lead us to know the degree of dynamism of the land cover changes by identifying land cover changes 'hotspots', which can constitute valuable information for regional planners and stakeholders working on the land.

In the literature, there are some interesting works that address landscape changes. Watson et al. (2014) summarize four key aspects of land cover change, namely (1) frequency of land-cover changes, (2) the sequence of land-cover types, (3) the time span over which each land-cover type extends, and (4) the magnitude of difference between land-cover types. Furthermore, Dimopoulos and Kizos (2020) study agricultural landscape changes through a mixed-methods approach. Another study, focused on Mediterranean tree-crops, analyzes dominant land use processes and their main drivers over the past 200 years (Wolpert et al., 2020).

In this context, geographic information science (GISc) plays a crucial role as a spatial foundation to develop these studies (Aplin and Smith, 2011). Thus, the development of methods for detecting land changes and quantifying them constitutes a central task, as previously mentioned, in at least one aspect: it allows the performance of analyses in a systematic way. However, auxiliary sources and methods can perfectly complement GISc, at the same time enriching the interpretation of the outcomes reached. This is the case of qualitative sources, methods and techniques (Santana-Cordero and Szabó, 2019). They strongly connect with history, an inescapable part of these studies, since they incorporate the temporal component in their analysis. A key question in these studies is to know well the different existing methods and techniques and how to combine them properly in a way that these different methods and their results complement each other.

This paper presents a method to quantify landscape dynamics using Corine Land Cover (CLC) datasets. The proposed method is applied to Gran Canaria island (Canary Islands, Spain), with each land unit (pixel, 5 m of spatial resolution) containing the number of times its land cover has changed in the period 1990-2018. However, statistical analysis of data has been done at a municipality level, which allows comparisons among municipalities and provides some useful results for regional planning and land management.

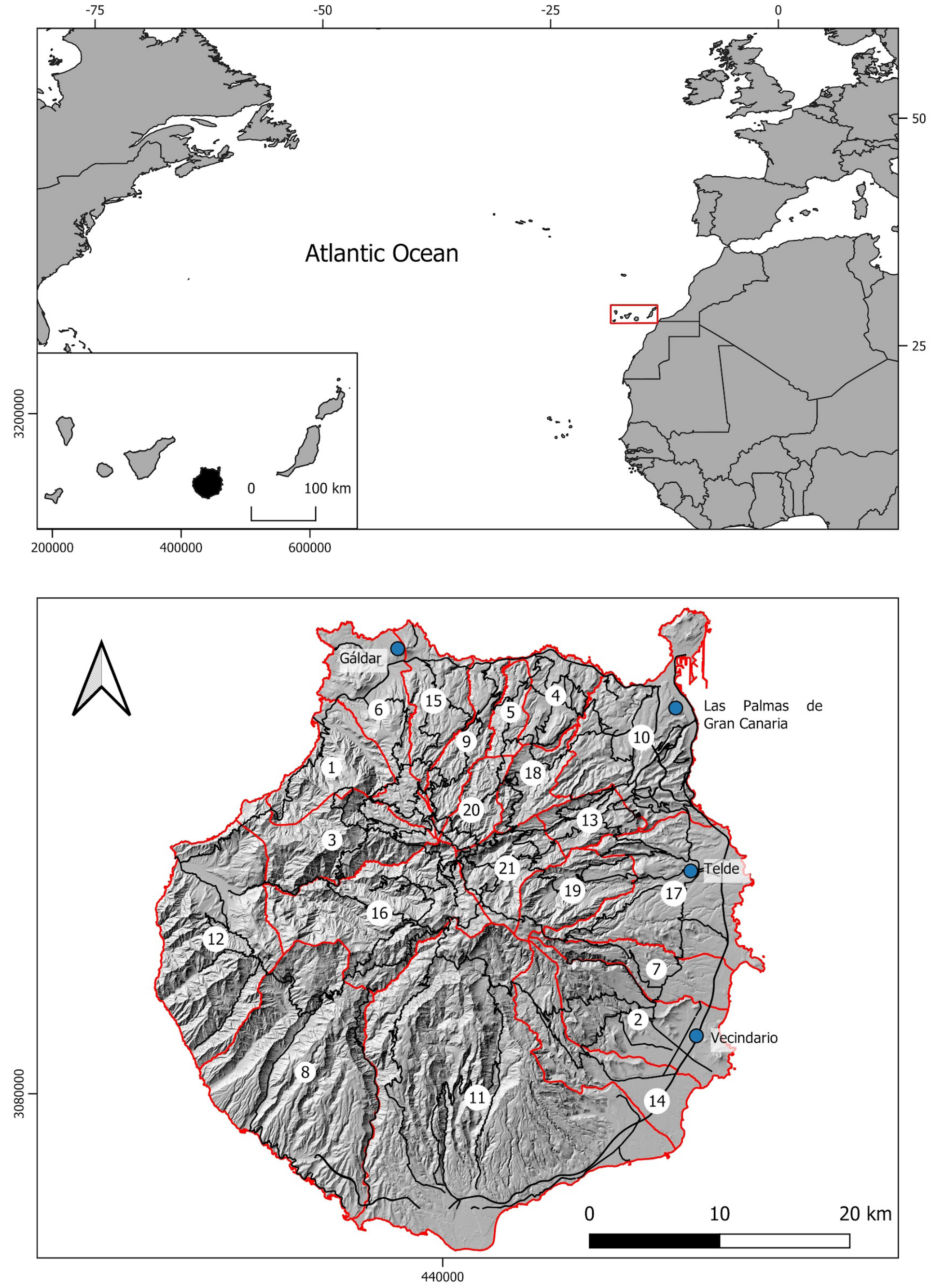
This research is focused on the first aspect of Watson et al. (2014), i.e., frequency of land cover change, and its objective is to characterize land cover dynamism and identify land cover change 'hotspots'.

2. Study area

Gran Canaria is one of the Canary Islands, an archipelago located in the north Atlantic ocean, near to the NW border of Africa (Fig. 1). The island has an area of 1560 km^2 and its highest point is in the center of the island at 1949 m above sea level. It has approximately one million inhabitants distributed throughout the whole island, but with a concentrated population of nearly 400 000 inhabitants in the capital city of Las Palmas de Gran Canaria (LPGC), situated in the island's

NE corner. The city was founded in 1478 after the Spanish had seized control of the island from the aboriginal inhabitants. The first settlements were located mainly in the NE of the island and the rest of the N sector. After the conquest, lands were distributed and many were converted into arable land for their exploitation. This agrarian economic model survived until the mid-XX century, when the arrival of tourism resulted in a major transformation of both the economy and the land. Nowadays, Gran Canaria is, together with other Canary Islands, a well-known and important tourist destination. In this context, it is of interest to consider the dynamism of its landscapes, which are changing at unprecedented rates.

Figure 1. Reference map and study area - Gran Canaria - with the different municipalities numbered. Key: (1) Agaete, (2) Agüimes, (3) Artenara, (4) Arucas, (5) Firgas, (6) Gáldar, (7) Ingenio, (8) Mogán, (9) Moya, (10) Las Palmas de Gran Canaria, (11) San Bartolomé de Tirajana, (12) La Aldea de San Nicolás, (13) Santa Brígida, (14) Santa Lucía, (15) Santa María de Guía, (16) Tejeda, (17) Telde, (18) Teror, (19) Valsequillo, (20) Valleseco, and (21) Vega de San Mateo.



3. Materials and methods

3.1. Materials

For the spatial analysis, the following sources were used: CLC datasets from 1990, 2000, 2012, 2018 (at 1:100 000 scale) obtained from the *Instituto Geográfico Nacional* (National Geographic Institute, Spain). For the statistical analysis, data on agricultural extension (from 2007, 2012 and 2018 - the years available), the number of tourists (1993-2018) and population data (1990, 2000, 2007, 2012 and 2018) were obtained from Istac [Statistics Institute of the Canary Islands] (2021) as well as other auxiliary data including municipality size for population density calculations. The year 2007 in the population variable was incorporated for correspondence and comparison purposes with agricultural data available.

3.2. Method: GIS-based land cover change analysis

Before starting the procedure, CLC vector layers have to be downloaded and prepared. As originally the layers have only the 3rd (the most detailed) CLC level in their attribute table, the other two taxonomic levels should be obtained, since the method presented requires them. Four CLC years were selected to perform the analysis: 1990, 2000, 2012 and 2018. In the first step, the intersection of each pair of consecutive time layers (i.e. 1990-2000, 2000-2012 and 2012-2018) is carried out. From this, 3 intersected layers are obtained: intersection_90-00 (i.e. 1990-2000), intersection_00-12, and intersection_12-18. Each intersected layer has the codes of the 3 levels of the two intersected years. For example, the layer intersection_90-00 will have CODE_90_L1, CODE_00_L1, CODE_90_L2, CODE_00_L2, CODE_90_L3 and CODE_00_L3 (CODE refers to CLC code). Then, three fields are added to the attribute table, each one indicating 0 or 1 for each intersection of each level (0 means no change, i.e. the same CLC code is in the two years intersected for a given polygon, and 1 means change). These new fields are named LD-L1 (landscape dynamics-level 1), LD-L2 and LD-L3. That is, we obtain three more fields in the attribute table (as previously mentioned) which will have a value of 0 or 1 for each intersection in the three levels (0 = no change (or persistence); 1 = change). In other words, polygons with the same category will have the value ‘0’, and polygons with different categories the value ‘1’.

Then, each intersected layer is converted into 3 binary rasters (spatial resolution of 5 metres) through a rasterize tool, with the same 0 or 1 value in each level. In total, 3 binary rasters are obtained (one for each level). These steps have to be repeated with the remaining consecutive year pairs of the CLC data layers (i.e. 2000-2012 and 2012-2018). Thus, we have three binary rasters per level, i.e. 9 rasters in total.

Next, all the rasters of the same level are summed up using the raster calculator to obtain a final raster with 0-3 range values, thereby acquiring one landscape dynamic raster for each level (Fig. 2 and 3). In these new rasters, each pixel contains the number of times that the land cover has changed during the study period (from zero to three) (Fig. 2). Again, this latter process should be repeated twice (with the other two levels). That is, we have to obtain three rasters of this latter type, one for each CLC level. At this point, we conclude the first part of the analysis, by carrying out a simple GIS operation to give us the number of pixels of each category (0-3) for these last rasters (once per level), which allows us to obtain the percentages of each category for the entire island, in each level.

The second step is to extract these raster data for each of the land units of our study (i.e. the municipalities) through the extraction of the number of pixels of each category for the 21 municipalities. As before, these data permit us to obtain the percentages, but in this case at the local level.

Figure 2. Workflow of the method used.

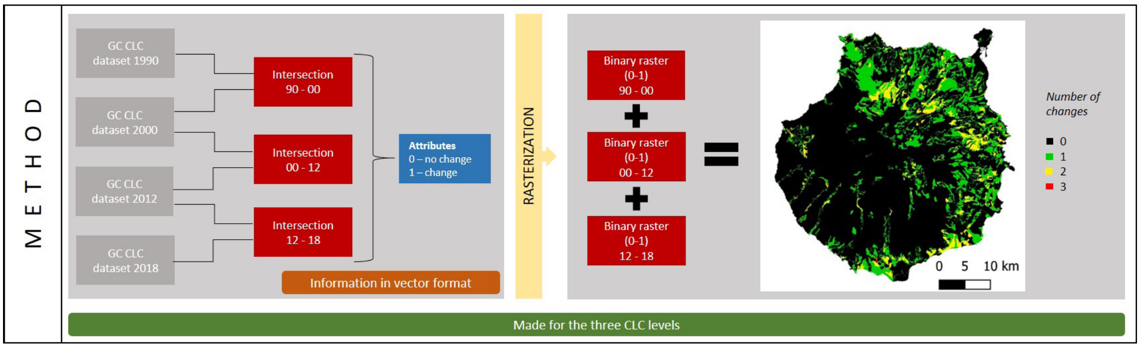
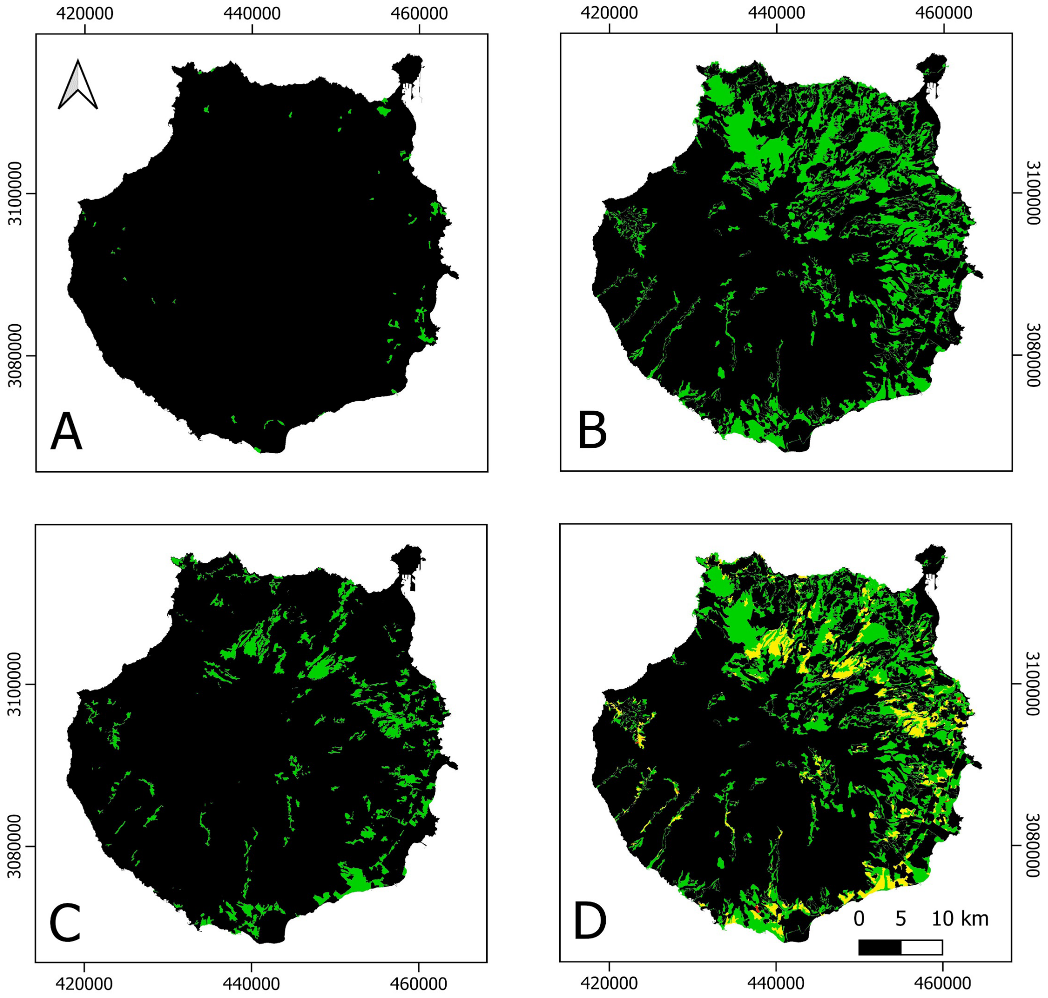


Figure 3. Summation of the three 0-1 binary raster layers (A: 1990-2000, B: 2000-2012, and C: 2012-2018) that produces the land cover dynamic raster (D), level 1. Key: black = no change; green = 1 change; yellow = 2 changes; red = 3 changes.



3.3. Statistical analysis

Some statistical data were again extracted per municipality (count, sum, mean, standard deviation and mode) but this time over the 9 binary rasters obtained (i.e. not over the three LD (landscape dynamics) rasters). Nonetheless, only the mean was used in the following operations. So, the data on landscape changes consisted of the mean value per municipality, with this being in the 0-1 range and called the average rate of change (ARC) for the three consecutive pairs of years (again in the three levels). The correlation is then determined between each ARC and the population density gains/losses in the three periods (i.e. 1990-2000, 2000-2012 and 2012-2018) and for each level. Only correlations with $R2 \geq 0.75$ were considered as showing the existence of a relationship (Ruiz Muñoz, 2004, p. 40). It should be noted that, despite the existence of a relationship, correlation does not imply causality.

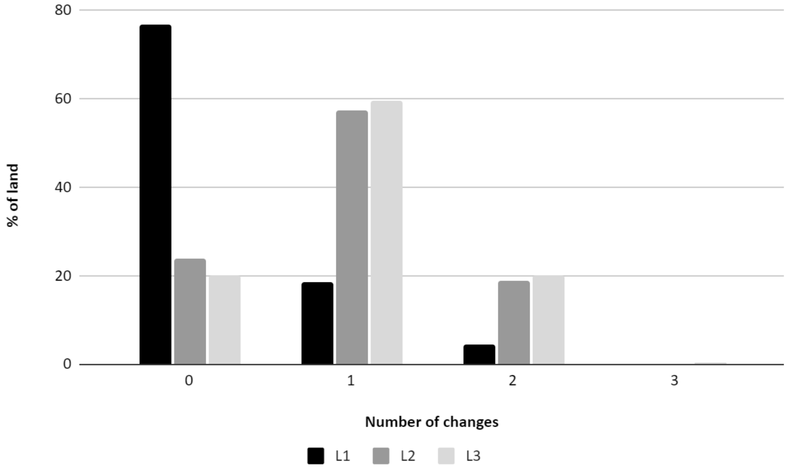
4. Results

Landscape changes over the whole island differ depending on the CLC level that is being considered (Table 1). The number of changes vary according to the level, with the 'no changes' (or persistence) category dominating in level 1, and the 'one change' category in levels 2 and 3. Spatially speaking, in level 1, in general, approximately the south-west half of the island presents 'no changes', with some exceptions, while the north-east part presents a 'no changes' - 'three changes' range. Regarding level 2, the scenario is completely different, with the different number of changes distributed around the island. The most dynamic areas are located to the east and near to the southernmost tip of the island. For level 3, the pattern is the same as the former, but with the disappearance of some 'no changes' areas. Regarding the differences, the scenario of level 1 is by some difference the most different with respect to the other two (Table 1 and Fig. 4).

Table 1. Percentage of the different categories in the three CLC levels and differences between pairs of levels. Key: "L" means level.

Categories (no of changes)/CLC levels (%)	L1	L2	L3	L1 - L2	L2 - L3	L1 - L3
0	76.87	23.70	20.01	53.16	3.69	56.85
1	18.64	57.41	59.63	-38.76	-2.22	-40.98
2	4.42	18.72	20.13	-14.30	-1.41	-15.71
3	0.05	0.15	0.21	-0.10	-0.06	-0.16
Total	100	100	100			

Figure 4. Percentage of each category in the three levels studied. Key: "L" means level.



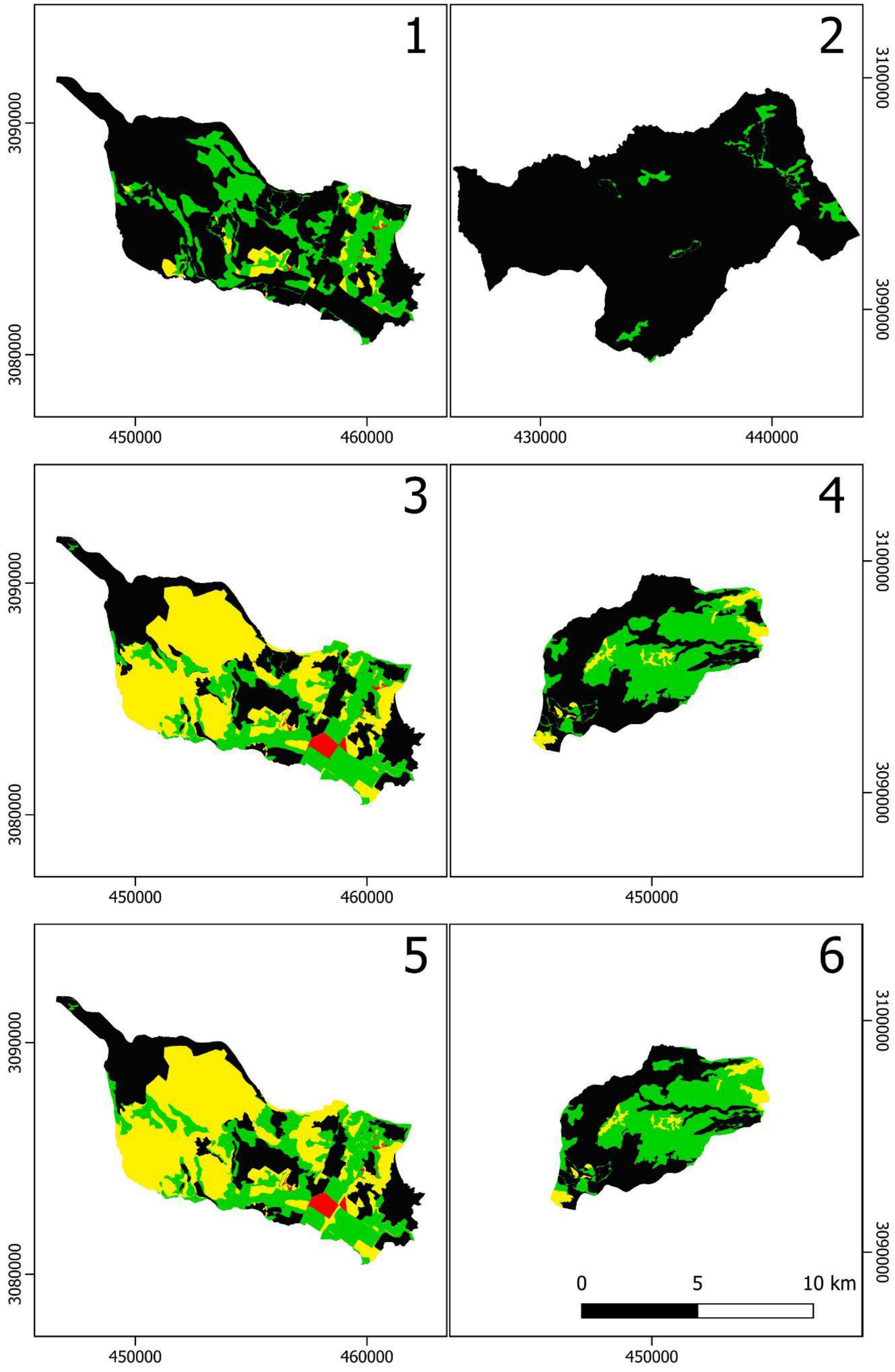
With respect to the results by municipality, the major differences between level 1 and levels 2 and 3 are again clear. In level 1, the most dynamic municipalities are Agüimes, Telde, La Aldea de San Nicolás, Arucas and San Bartolomé de Tirajana, while the least changing are Tejeda, Artenara, La Aldea de San Nicolás, Mogán and Agaete. As for level 2, the most dynamic are Agüimes, Telde, Las Palmas de Gran Canaria, Gáldar and Arucas, although La Aldea de San Nicolás and San Bartolomé de Tirajana have the same percentage as the last two. The least changing municipalities in level 2 are Valsequillo, Ingenio, Las Palmas de Gran Canaria, Vega de San Mateo and Santa María de Guía. Finally, in level 3, the most dynamic municipalities are Agüimes, Telde, Santa Lucía, Santa María de Guía and Las Palmas de Gran Canaria, while the least changing are Valsequillo, Vega de San Mateo, Las Palmas de Gran Canaria, Ingenio and Agüimes. In the intermediate categories (1 and 2 changes), Gáldar and Moya respectively rank highest in level 1 (although with low percentages), while Mogán and La Aldea de San Nicolás rank highest (respectively for 1 and 2 changes) in levels 2 and 3 with percentages above 80% (Table 2 and Fig. 5).

It should be noted that it is totally compatible for the same municipality to be among the most dynamic and the least changing, although in all cases the percentages in category 0 (unchanging or persistence) are much higher than those in category 3, especially in level 1.

Table 2. Percentage of the different categories in the three CLC levels per municipality. Top 5 in each field in bold.

	L1				L2				L3			
Municipality	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
Agaete	**85.9**	13.9	0.1	0.0	30.5	**69.2**	0.3	0.0	28.1	**70.6**	1.3	0.0
Agüimes	70.2	25.5	4.1	**0.2**	33.9	24.7	**40.0**	**1.4**	**30.8**	26.5	**41.3**	**1.4**
Aldea de San Nicolás (La)	**92.5**	5.2	2.2	**0.1**	8.4	**82.9**	8.6	0.1	6.8	**84.2**	8.9	0.1
Artenara	**93.4**	6.2	0.3	0.0	30.0	48.0	**21.9**	0.0	29.9	45.6	**24.4**	0.0
Arucas	53.4	**42.1**	4.4	**0.1**	28.2	60.3	11.4	**0.1**	25.8	62.7	11.4	0.1
Firgas	49.8	**46.6**	3.5	0.0	27.3	**68.2**	4.5	0.0	25.4	67.7	6.9	0.0
Gáldar	41.2	**53.2**	5.6	0.0	17.4	**70.5**	11.9	**0.1**	16.3	**71.2**	12.3	0.1
Ingenio	60.8	32.8	6.4	0.0	**42.6**	44.3	13.1	0.0	**31.5**	52.3	16.1	0.1
Mogán	**92.4**	6.6	1.0	0.0	13.5	**83.3**	3.2	0.0	11.8	**84.3**	3.8	0.0
Moya	48.5	31.0	**20.4**	0.0	28.6	43.0	**28.4**	0.0	25.4	45.4	**29.2**	0.0
Palmas de Gran Canaria (Las)	63.1	**33.7**	3.2	0.0	**40.9**	48.9	10.0	**0.2**	**32.2**	57.1	10.5	**0.2**
San Bartolomé de Tirajana	83.2	11.9	4.8	**0.1**	12.0	66.7	21.2	0.1	8.5	**68.7**	22.7	0.1
Santa Brígida	49.2	**37.8**	**13.0**	0.0	22.3	59.0	18.7	0.0	17.7	63.7	18.7	0.0
Santa Lucía	78.5	19.5	2.0	0.0	**37.8**	31.6	**30.6**	0.0	28.4	36.7	**34.2**	**0.7**
Santa María de Guía	71.7	23.5	4.8	0.0	31.9	62.2	5.8	0.0	26.7	65.1	7.9	**0.2**
Tejeda	**96.8**	3.2	0.0	0.0	23.1	13.1	**63.8**	0.0	23.0	13.2	**63.8**	0.0
Telde	59.6	27.0	**13.2**	**0.2**	29.5	52.8	17.3	**0.5**	22.3	53.9	23.1	**0.7**
Teror	53.1	33.4	**13.5**	0.0	27.4	57.9	14.7	0.0	23.2	60.4	16.4	0.0
Valleseco	70.9	20.0	**9.1**	0.0	25.5	60.2	14.3	0.0	24.6	59.7	15.7	0.0
Valsequillo	79.9	17.5	2.6	0.0	**54.3**	39.6	6.1	0.0	**50.3**	43.3	6.4	0.0
Vega de San Mateo	69.3	27.7	3.0	0.0	**38.2**	50.3	11.6	0.0	**32.5**	55.8	11.7	0.0

Figure 5. Most dynamic and least changing municipalities for each level.
Key: 1, Agüimes (Level 1, most dynamic); 2. Tejeda (L1, least changing); 3. Agüimes (L2); 4. Valsequillo (L2); 5. Agüimes (L3); and 6. Valsequillo (L3). Black = no change; green = 1 change; yellow = 2 changes; red = 3 changes. Note: north and scale bar are the same for all the maps.



At island level some spatial patterns can be seen. Firstly, coast-countryside dichotomy is observed. While, for level 1, 2 and 3 changes dominate in the north-east of the island, with this being slightly more important in countryside areas, in the south-west of the island there is clear dominance of land cover changes in coastal areas and throughout the biggest ravines. Levels 2 and 3 are very similar again. In this scenario, practically all the island has experienced changes, with the central-west part and the south-east fringe large areas dominated by 2 changes. In terms of the aforementioned dichotomy, countryside areas are more dynamic than coastal ones.

Furthermore, for the same levels and focusing now on urban-natural areas, consolidated urban areas and an important part of protected natural areas (PNAs) are dominated by the 'no change' category. In this sense, the cases of part of the city of Las Palmas de Gran Canaria, and the PNA of Inagua forest, part of Tamadaba forest and Maspalomas dune field are very significant. It is also notable that there are large areas of PNAs with 1 or 2 changes. On the other hand, the most dynamic areas, those with 3 changes, are generally associated with urban areas and proximity to the coast, although they are not important in terms of extension.

At municipal level and with respect to Figure 5, spatial patterns can be explained in more detail. Regarding maps 5.1, 5.3 and 5.5, the municipality of Agüimes shows a certain uniformity in the number of changes throughout its territory at level 1 (5.1). However, levels 2 and 3 (5.3 and 5.5, respectively) show a dominance of '2 changes' in countryside areas, making them more dynamic than the coast. In the case of Tejeda (5.2), as a low changing municipality at level 1, its dynamism can be explained by the presence of PNA throughout its area. For its part, Valsequillo (5.4 and 5.6) concentrates almost all its dynamism in the center and east of the municipality.

4.1. Statistical correlations and analysis of trends

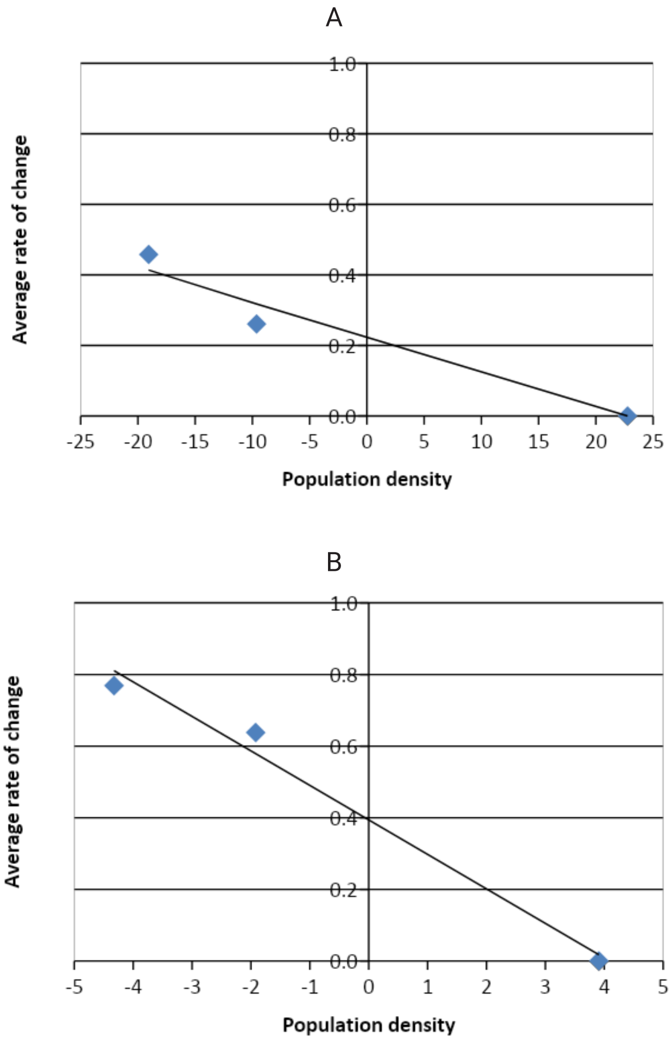
Correlations can serve as an indicator to complement the results of the spatial analysis performed. Furthermore, similarity of trends can support the results. Table 3 shows the correlations between ARC and population density (PD) gains/losses for all municipalities and levels. Shown in bold are the municipalities with R^2 >= 0,75: Artenara (all levels), Ingenio (levels 2 and 3), Mogán (levels 2 and 3), Moya (all levels), Las Palmas de Gran Canaria (all levels), Tejeda (levels 2 and 3), Vallesego (level 1) and Vega de San Mateo (all levels). On average, top-5 municipalities that present the highest correlations are Las Palmas de Gran Canaria, Moya, Artenara, Tejeda and Vega de San Mateo. It is therefore concluded that all the aforementioned municipalities present coherence between the results of the spatial analysis and population density data.

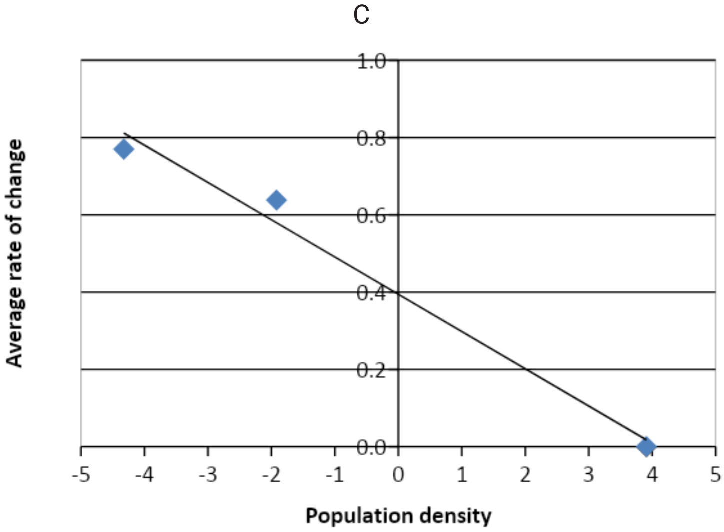
Table 3. Correlation between average rate of change (ARC) and population density (PD). $R^2 \geq 0.75$ in each field in bold.

Municipality	L1 R2	L2 R2	L3 R2	Mean
Agaete	0.09	0.10	0.08	0.09
Agüimes	0.64	0.12	0.14	0.30
Aldea de San Nicolás (La)	0.06	0.46	0.46	0.33
Artenara	**0.86**	**0.88**	**0.91**	**0.88**
Arucas	0.21	0.31	0.31	0.28
Firgas	0.12	0.06	0.05	0.08
Gáldar	0.54	0.52	0.51	0.52
Ingenio	0.62	**0.76**	**0.82**	0.73

Municipality	**L1 R2**	**L2 R2**	**L3 R2**	**Mean**
Mogán	0.52	**0.75**	**0.75**	0.67
Moya	**0.95**	**0.89**	**0.88**	**0.90**
Palmas de Gran Canaria (Las)	**0.94**	**0.98**	**0.97**	**0.96**
San Bartolomé de Tirajana	0.15	0.43	0.44	0.34
Santa Brígida	0.41	0.28	0.26	0.32
Santa Lucía	0.58	0.30	0.39	0.42
Santa María de Guía	0.40	0.24	0.24	0.29
Tejeda	0.53	**0.98**	**0.98**	**0.83**
Telde	0.07	0.25	0.24	0.19
Teror	0.03	0.11	0.11	0.08
Valleseco	**0.80**	0.69	0.70	0.73
Valsequillo	0.05	0.01	0.00	0.02
Vega de San Mateo	**0.86**	**0.79**	**0.80**	**0.82**

Figure 6. Average rate of change - Population density correlations. Municipalities with the highest fits in the three levels (A: Moya (L1; $R^2 = 0.9495$); B: Tejeda (L2; $R^2 = 0.9836$); C: Tejeda (L3; $R^2 = 0.9838$)). Note that Tejeda and Las Palmas de Gran Canaria have the same value in Table 3 - L2, but the latter is lower at a higher number of decimal points (i.e. 0.978).

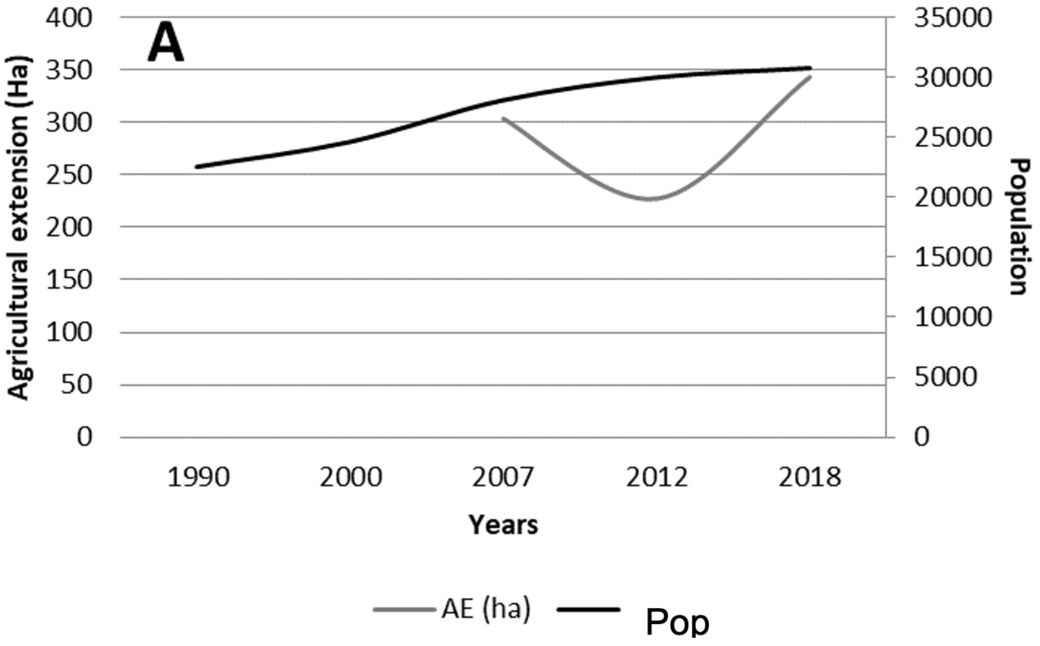


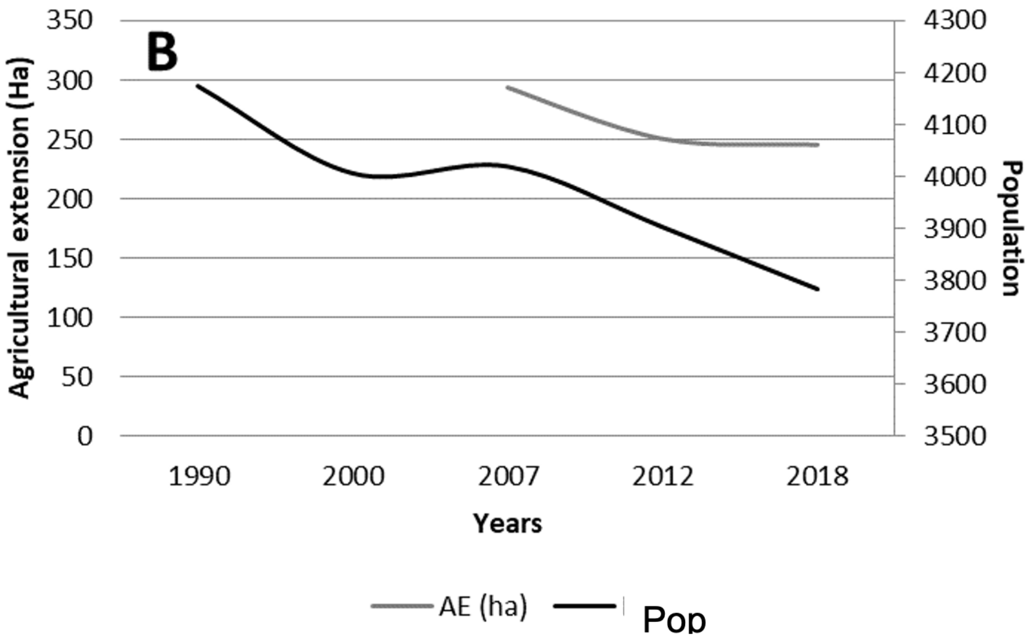


The three cases shown in Figure 6 show the strong relationship between ARC and PD. Thus, ARC decreases when PD increases. It would be logical to expect that the fewer people in the municipalities the less land changes, but in these cases there is an increase in the changes.

With respect to the agricultural extension (AE), a general pattern is observed in the 2007-2012-2018 period, with the values falling in 2012 and rising again in 2018 to similar levels to those of 2007. Agaete, Artenara, Valsequillo, Valleseco and Vega de San Mateo are the only municipalities that do not follow this pattern. Therefore, no specific relationship can be established between AE and the population data, due to the lack of similarity among the trends except in the most clear cases of Valleseco and Valsequillo. Additionally, Gáldar is the municipality with the largest agricultural extension and Artenara the lowest. Figure 7 shows two examples of the trends of AE and population data.

Figure 7. AE and population data trends. A: Ingenio (example showing the general pattern identified); and B: Valleseco (example not following the general pattern identified).



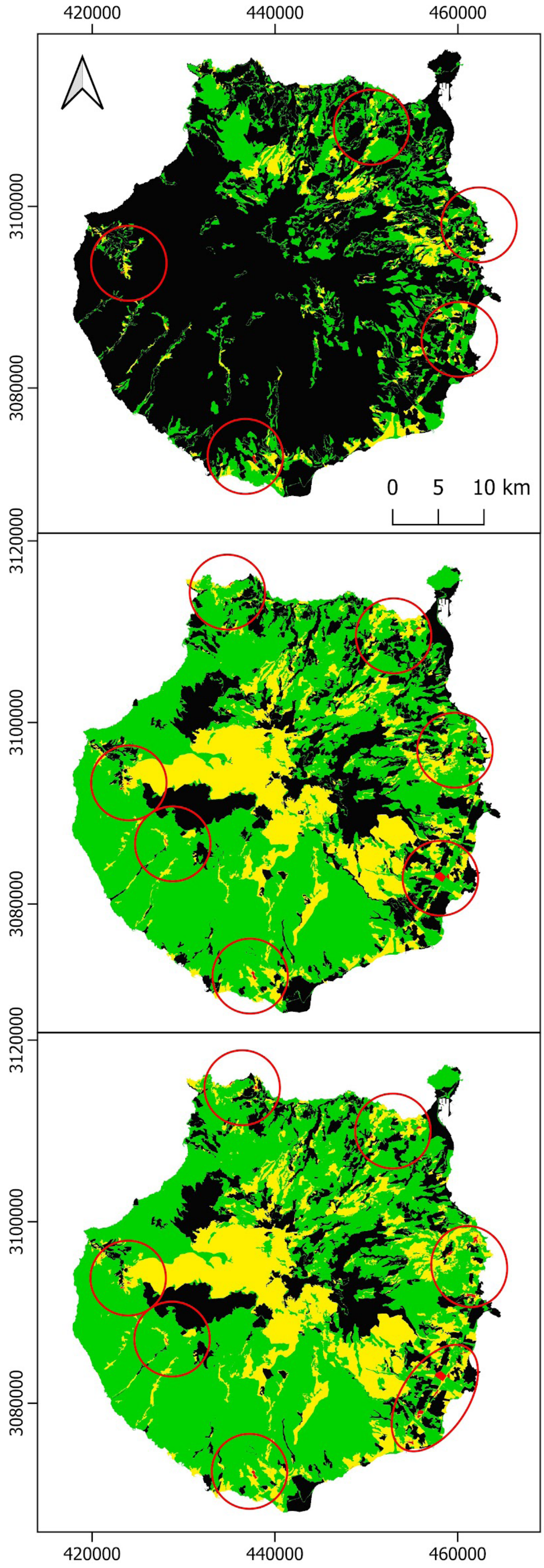


Given the general nature of the data (at island level), it is not possible to establish a relationship between the number of tourists and the ARC of each municipality. However, in a previous study by the same author a growth trend was observed (for the 1993-2018 period), with a particularly notable increase in the 2013-2016 period (increase of 1 017 669 tourists) (Santana-Cordero 2021). This influences above all the two southernmost municipalities (Mogán and San Bartolomé de Tirajana), where the main tourist resorts in the island have been established.

4.2. Land cover change 'hotspots'

Land cover change 'hotspots' (Fig. 8) indicate the most dynamic areas in terms of land cover change. As can be observed, almost all the 'hotspots' are located near the coast, except those located in the west of the island, which are slightly inland. Again, level 1 differs from 2 and 3, with the 'hotspots' more numerous in the latter two. In the countryside of the island there are no 'hotspots' due to the persistence guaranteed by PNAs and its mountainous character.

Figure 8. Land cover change 'hotspots' identified in the three CLC levels. Top: level 1; center: level 2; bottom: level 3.



5. Discussion

5.1. Land cover changes: exploring possible explicative factors

Some comments of interest can be made on the findings of the present study. Figure 6 shows an increase in land change as population density decreases. This may be related to land covers that do not imply residential use, or in other words people acting in these lands but not living in them. An alternative explanation could be related to an increase in the number of people owning a second residence (e.g. for vacation purposes) and acting in a municipality different to that of their main residence. This would mean that the people involved in the changes would not be registered as being resident in these municipalities.

Moreover, it should be noted that land abandonment can trigger changes in land covers, since an abandoned agricultural land would experience changes in the vegetation. Other transformations may be related to old abandoned/unused agricultural fields transformed into new industrial estates or big parks, which provoke land changes but not necessarily an increase of population, since workers or users can live in other areas. This last phenomenon has happened in the municipality of Agüimes and Las Palmas de Gran Canaria. Another case is the transformation of these old abandoned/unused lands into residential areas, as is the case of the coast of Telde.

On the other hand, the two patterns identified in the analysis of trends (Fig. 7) reveal relationship between the population data and agricultural extension, i.e. when the first grows the second also grows. Taking into account that the two municipalities shown in Figure 7 are mainly rural (Ingenio and Valleseco), it is expected that people living in them practice agriculture, whether for commercial purposes or for self-consumption. Again, second residences can play an important role in these contexts, above all as self-consumption mode. One particularity of these data is the fall that agriculture experienced in 2012 in almost all the municipalities of the island. Although the reasons behind this fall are beyond the scope of the present study, it constitutes an important event that surprisingly interrupts the trend of agricultural extension following that of population at municipality level.

Although it may be argued that this work only encompasses very recent landscape history (from 1990 to 2018), it nonetheless constitutes a diachronic study that focuses on the interaction between a society and its environment. In this line, there are an important number of studies that have contemplated changes and persistence in landscape dynamics, and the factors that trigger them (Bürgi et al., 2015, 2017; Lieskovský and Bürgi, 2018; Domon and Bouchard, 2007).

The major historical events in Europe, such as World War II and Soviet socialist policies, have undoubtedly influenced landscape development from the mid-XX century to current times (Malandra et al., 2019; Plieninger and Schaich, 2014; Biró et al., 2013). In the particular case of Spain, although technically neutral in World War II, the country suffered a civil war (1936-1939) and a dictatorship (1939-1975) which strongly influenced landscape development (Santana-Cordero et al., 2016; Cardesín, 2016). Subsequently, a democratic transition happened which has been an important influence on Spain (and of course Gran Canaria) for the study period adopted. This is shown in some findings of this study, such as the hotspots, identified as highly dynamic areas in terms of land cover change, and the increase in the number of tourists.

One event which directly affected the landscape changes considered in our study was the passing of Act 12/1987, dated 19 July, on the Declaration of Natural Areas in the Canary Islands, which limited man-made changes to protected Nature Reserves. In this study, the persistence of some landscapes related to PNAs have been confirmed, above all those with the strongest protection (case of Inagua Nature Reserve). In addition, the economic crisis of 2008 also stopped man-made landscape changes, and can be considered a persistence-causing factor, and is likely linked to the fall registered in the AE of 2012.

Finally, the identification and mapping of land cover change 'hotspots' could aid the regional planners and the stakeholders in their task of managing the land, and to understand visible land changes for the period 1990-2018.

5.2. Methodological issues

Reed et al. (2020) state that methodological guidance is missing in integrated landscape studies. This claim is not new, since other authors have highlighted the need to provide more methodological contributions, both quantitative and qualitative (Bürgi and Russell, 2001), and unify methodologies in historic landscape studies (Szabó, 2015). This would lead to a better understanding of landscape dynamics and constitute a valuable tool for landscape management (Moombe et al., 2020).

The classification of land units, in pixels or polygons, according to the number of times their land cover has changed during a study period is a way to measure one aspect of landscape dynamism. It is useful, among other applications, for identifying land cover change 'hotspots', indicating where land functions as a really changing element.

Close and detailed observation of the methodological process has provided some interesting feedback in terms of advantages and drawbacks. On the one hand, the existence of three taxonomic levels in the CLC nomenclature, and the application of the method in all three, yields an enormous quantity of data for analysis. As for the levels, it should be noted that the more detailed the cartography and categories, the more changes the method detects. That justifies the use of pixels of 5 m, which also provides more detailed borders in the rasterization process. This is a clear conclusion and one of the reasons for the major differences seen between level 1, and levels 2 and 3 for the whole island in terms of changes (Table 1, Fig. 5). Furthermore, the quality and characteristics of the satellite imagery used to develop the CLC cartography, as well as the change in the methodology for obtaining them from 2006 onwards (García-Álvarez and Camacho-Olmedo, 2017, 2023), have greatly influenced the result. In this line, it would be logical to conclude that there have been important differences between the characteristics of the images of the 1990s and the 2010s that improve the CLC maps.

On the other hand, an important limitation of the method arises when we obtain results in three levels (three analyses with different results/maps). Which level/s should be taken into account? Since each level is based on different degrees of detail, the specific interest/s of the researcher may correspond to one (or more) level depending on the particular aims of the study in question. Another drawback is that CLC maps have been done for less detailed scales than used in this method. Furthermore, this method incorporates the possible mistakes that might exist in the source map. However, a more detailed scale does not impair the analysis of this study. Another constraint is in the statistical procedure, since the R^2 correlations shown in the figure 6 are supported only by 3 points, not being possible to add more because there is no more data.

The method presented here could be categorized as an object-based technique through GIS. This type of method has been tested and proven to be effective in the detection of land changes (Browning et al., 2011; Radoux et al., 2011), as was reported at a meeting held to 'bring together practitioners in remote sensing, GIS and environmental science to identify best practice in the development and application of object-based landscape analysis techniques' (Aplin and Smith, 2011). Moreover, the validity of CLC cartography is endorsed by quality works that have been published by researchers (e.g. Gerard et al., 2010). Additionally, other works have conducted studies on the quantification of historical landscape change, assessed in terms of accuracy (e.g. Bayr, 2021).

6. Conclusions

This work presents a way for the study of land cover dynamism based on official cartography and automated GIS-based processes. The method allows analyses of land change to be made systematically, ensuring objectivity in their determination. It also allows the detection of land cover change 'hotspots', information of potential interest for landscape management and regional planning. Furthermore, the findings of studies carried out with this method yield data that offer opportunities for the development of further works of their interpretation.

Results of this study help to understand how the land cover of Gran Canaria has changed during the period 1990-2018, particularly in relation to socioeconomic and political situations, as mentioned in the discussion. Moreover, the importance of the relationship of historical events can be seen in the dynamism of the studied land cover, supporting the argument that land is dynamic and its character is the result of many factors (e.g. human activities, economic and political events, and their interaction with the landscape).

This is the first time that a study of this type has been performed for Gran Canaria. It is intended to carry out further analysis and derive new results from all the data generated in this study in future investigations. This would allow for deeper analyses and the drawing of new conclusions that could be of application for regional planning and land management.

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