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Assessing Urban Landscape Composition and Configuration in the Pearl River Delta (China) over Time

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Abstract: When used to comprehend how a region changes over time, landscape metrics serve as a precious tool for generating knowledge on transformation dynamics of the spatial patterns and for gaining insights on the heterogeneity of its composition. The paper presents the case study of the Pearl River Delta (China). The composition and configuration of the urban landscape using four landscape metrics to compare the evolution of the region's cities over the period 1992-2015 is examined. ESA CCI land cover maps are used. We argue that when used together with mapping, landscape metrics can improve the understanding of trends and rates of land conversion and support practitioners and decision-makers in the development of landscape-based strategies for future-oriented actions.

Keywords: Landscape metrics, interpreting spatial information, dynamics of change, GIS, map analysis

1 Introduction

Fast urbanizing deltas are crucial global economic key nodes and areas of inestimable ecological value. Characterized by high dynamicity both from a natural and anthropic perspective, they act as magnets for people and serve as technological and innovation hubs. The presence of water in these regions has constituted the main condition for humankind to thrive, taking advantage of the fertility of the soils and the richness of the ecosystems. However, at the same time, deltas are particularly sensitive environments characterized by extreme fragility and prone to multiple natural threats, worsened by the impacts of climate change. Furthermore, fast economic development and uncontrolled urbanization in deltaic areas result in the intensification of urban land use, leading to the exacerbation of their physical vulnerability, in terms of flood risk and reduction of ecosystem services.

To ensure a more sustainable future for deltaic regions, spatial strategies are needed to increment their ability to cope with their vulnerabilities and at the same time strengthen their capacity to face natural and human-made threats. In this regard, the investigation of a region's physical form is essential in order to implement strategies and principles able to deal with the existing situation and guarantee a spatio-temporal continuity, bridging the past with the future, and enabling the landscape to accommodate human activities without being irremediably altered (MCHARG 1969, NEUMAN 2000). Therefore, the temporal dimension is crucial to understand the dynamics of development and change of a region. Mapping and landscape visualization are extremely powerful tools to carry a systematic study of deltaic landscapes undergoing through urbanization, to generate and visualize knowledge on the complex interactions that characterize them (XIONG & NIJHUIS 2018). Integrating such tools with metrics that make use of land cover maps for comparing the landscape of different parts of a region can help to provide more insightful information on similarities and dissimilarities of spatial patterns on a temporal perspective, looking into trends and dynamics of change to generate knowledge that can serve as a base for decision-makers. In this sense, coupling landscape

metrics with mapping becomes a valuable operation to better engage with the complexity and the pace of such dynamics of transformation, by quantifying and visually communicating the variation in magnitude of certain phenomena, such as the impact of human activities on a geographical area.

This paper aims at connecting and understanding of the landscape transformation process through the use of landscape metrics and their spatial representation. The Pearl River Delta (PRD) (China) as one of the fastest urbanizing deltas in the world is used as a case study. Open source ESA CCI Global Land Cover data from 1992 to 2015 is employed to analyse and visualize the changing configuration and composition of the urban landscape in terms of quantity and quality.

The paper consists of five parts. In the following section, a description of the used landscape metrics is provided. Thereafter, the data and methods are presented, followed by the results of the analysis. Finally the paper ends with a discussion and conclusions.

2 Landscape Composition and Configuration Metrics

The structure of a landscape is defined by a particular spatial pattern consisting of two main components, composition and configuration. Composition refers to the non-spatial aspects of a landscape. In other words, by what a landscape is made of, and how much of it is there. Configuration concerns the spatial character of a landscape, the mutual relationship between its elements and their physical arrangement. Together, these two attributes determine both the spatial structure and the heterogeneity of a landscape, and are the two most fundamental measures of landscape patterns and functioning.

Over time, a large number of metrics have been developed to assess changes in landscape structure and its performances, such as, for instance, connectivity as a result of fragmentation, landscape division, splitting. Landscape metrics can be employed for comparing both the structure and the form of urban areas (PRASTACOS et al. 2011) and quantify landscape variations over time (NEEL et al. 2004), supporting the understanding and the monitoring of changes in spatial patterns, as well as the change in ecological condition of the landscape (NEILL et al. 1997).

For this study, the analysis of urban development was carried out using five metrics. The selected metrics describe different characteristics of the landscape, at the class level, such as the size and the number of the patches composing a specific landscape class, representing the basic information to gain knowledge on landscape patterns. These landscape metrics are used (MCGARIGAL et al. 2012):

- Total (Class) Area (CA) gives a quantification of the landscape comprised of a particular patch type, therefore is a fundamental measure of landscape composition. The unit of the metric is expressed in hectares. This metric is a simple but useful measure to understand how much land changed over time.
- Percentage of Landscape (PLAND) quantifies the proportion of each patch class in the landscape. It is a relative measure, so it can be employed to assess and compare the landscape composition among landscapes of varying size.
- Number of Patches (NP) expresses the levels of fragmentation of a patch class.
- Mean Patch Area (AREA_MN) is a class distribution statistics based on the average size of the patches belonging to the same class.

- Euclidean nearest neighbour distance (ENN_MN) provides information on the degree of isolation of the patches of a particular class, returning the mean value for each class type.

3 Materials and Methods

3.1 Study Area: The Pearl River Delta

The Pearl River Delta (21°34' N to 23°56' N, 111°58' E to 114°38' E) is located in the Guangdong province on the southern coast of China. It constitutes of 9 mega cities, Guangzhou, Shenzhen, Foshan, Dongguan, Huizhou, Jiangmen, Zhaoqing, Zhongshan, and Zhuhai, and two Special Administrative Regions (SARs), Hong Kong and Macao. Since the implementation of the *open door* policy, in 1979, the PRD has experienced an incredible economic development which brought the delta to become one of China's leading economic regions and a major manufacturing hub, gaining the status of 'world factory'. In addition, it coincided with an as much as an astonishing urban growth that made it the world's largest urban area both in terms of size and population, overtaking the Greater Tokyo Area in 2014 (WORLD BANK 2015). With the implementation of this reform, the shifting from a state-monopoly economy to a market-driven one and the sudden growth of the industrial sector generated a vast impact on the countryside through a rapid and scattered process of change in land use which transformed the farmland into urban settlements, affecting the fragile balance of such water-dominated environment, worsening the quality of the rivers and jeopardising the capacity to manage water (NIJHUIS et al. 2019).

The spatial transformation to which the PRD underwent abruptly and irreversibly changed the region's landscape at both the regional and local scales. At the regional scale, the designation of Shenzhen and Zhuhai as Special Economic Zones (SEZs) initiated a process of spatial restructuring that saw the emergence of two main urban axes along the eastern and western coasts of the delta. On a smaller scale, the transition from a production model based on agriculture to manufacture gave birth to a peculiar type of development known as 'rural industrialization' (LIN 1997), which saw the extensive transformation of patches of natural and agricultural landscapes into urban areas.

The appearance of a growing number of small and medium complexes of urban and industrial settlements in the floodplain was the result of spontaneous actions aiming at maximizing the economic benefit of the agricultural products, prompted by the increasingly thicker web of transportation infrastructure. Therefore, people living in the rural areas begun a process of conversion of agricultural landscape, characterized by the presence of dike-ponds utterly ignoring the natural and cultural traits of the territory. Nowadays, the PRD is a seamless conurbation in which it is hard to trace a neat boundary between city and countryside. Dense urban areas and countless small- and medium-size settlements encroach the agricultural and the natural land, eroding the natural landscape and exposing the region to increasing flood risks.

3.2 Data

In this study, time-series datasets on land cover are used to explore the landscape changes. In particular, the land cover classification gridded maps provided by the European Space Agency (ESA) Climate Change Initiative (CCI) covering the period from 1992 to 2015 were acquired. The global land cover maps have a spatial resolution of 300 meters, and describe

the land surface categorizing it into 22 different classes. The dataset provides homogeneous geographic information on the whole delta, including Hong Kong and Macau. The coordinate reference system used for the global land cover database is a geographic coordinate system (GCS) based on the World Geodetic System (WGS 84) reference ellipsoid. Prior to analysis and interpretation, geometrical rectification was performed.

3.3 Method

The different time stages of the same dataset were first clipped according to the extent of the administrative boundaries of the cities and the SARs object of this study. After the clipping, the total number of land-use classes was 20.

In the second step, data processing consisted of the reclassification of CCI-LC product using QGIS. The 22 classes were then grouped and reclassified into the seven land categories, based on the classification proposed by IPCC. The final classes were: agriculture, irrigated cropland, forest, grassland, wetland, settlement, and other land (see Table 1). The irrigated or post-flooding cropland was treated as a class *per se*, as it provides spatial information on the location of the dyke-ponds and the paddy fields over the delta.

Table 1: Land cover classes derived from the reclassification of the CCI-LC maps

Reclassified rasters		LCCS classes used in the CCI-LC maps
Value	Description	description
1	Agriculture	10. Cropland, rainfed; 11. Herbaceous cover; 12. Tree or shrub cover; 30. Mosaic cropland (>50 %) / natural vegetation (tree, shrub, herbaceous cover) (<50 %); 40. Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50 %) / cropland (<50 %)
2	Irrigated Cropland	20. Cropland, irrigated or post-flooding
3	Forest	50. Tree cover, broadleaved, evergreen, closed to open (>15 %); 60. Tree cover, broadleaved, deciduous, closed to open (>15 %); 61. Tree cover, broadleaved, deciduous, closed (>40 %); 62. Tree cover, broadleaved, deciduous, open (15-40 %); 70. Tree cover, needleleaved, evergreen, closed to open (>15 %); 71. Tree cover, needleleaved, evergreen, closed (>40 %); 72. Tree cover, needleleaved, evergreen, open (15-40 %); 80. Tree cover, needleleaved, deciduous, closed to open (>15 %); 81. Tree cover, needleleaved, deciduous, closed (>40 %); 82. Tree cover, needleleaved, deciduous, open (15-40 %); 90. Tree cover, mixed leaf type (broadleaved and needleleaved); 100. Mosaic tree and shrub (>50 %) / herbaceous cover (<50 %); 160. Tree cover, flooded, fresh or brakish water; 170. Tree cover, flooded, saline water
4	Grassland	110. Mosaic herbaceous cover (>50 %) / tree and shrub (<50 %); 130. Grassland
5	Wetland	180. Shrub or herbaceous cover, flooded, fresh/saline/brakish water
6	Settlement	190. Urban areas
7	Other	120. Shrubland; 121. Shrubland evergreen; 122. Shrubland deciduous; 140. Lichens and mosses; 150. Sparse vegetation (tree, shrub, herbaceous cover) (<15 %); 151. Sparse tree (<15 %); 152. Sparse shrub (<15 %); 153. Sparse herbaceous cover (<15 %); 200. Bare areas; 201. Consolidated bare areas; 202. Unconsolidated bare areas; 210. Water bodies; 220; Permanent snow and ice

After aggregating and reclassifying the information, the third step envisaged the simplification of the data to remove smaller raster polygons that could invalidate the analysis. This has been done using the Sieve algorithm in QGIS to replace the undesired pixel with the pixel value of the largest neighbour polygon representing the specific landscape classes, and resulted in the elaboration of 24 land cover maps, of which Figure 2 offers a sample.

In order to assess and compare the urban landscape composition and configuration for the cities, landscape metrics identified by MCGARIGAL et al. (2012) and described in section 1.1 were used. The computation of the above mentioned landscape metrics were performed using FRAGSTATS 4.2 on raster datasets as an input for each class of landscape defined.

The data has been organized with the help of R Studio 3.5.1, QGIS 3.4.12 and then edited with Illustrator CS6.

4 Results and Discussion

The analysis performed on the 9 cities and 2 SARs of the case study for the time between 1992 and 2015 showed how the variation in urbanization happened unevenly in the region. When looking at the total class area (CA) metric, in 1992 Shenzhen was the most urbanized city, with a total area of 10.638 ha, but in 2015 was surpassed by Guangzhou (35.856 ha), Dongguan (35.451 ha), and Foshan (34.821 ha). The cities which the highest rate of urbanization are Zhongshan (534.92 %), Huizhou (428.88%) and Dongguan (380.36 %), whereas the Hong Kong, Macao, Shenzhen and Guangzhou present the lowest rate (see Table 2). However, looking at the PLAND metric (Fig. 2), the process of land conversion to urbanized areas happened differently from city to city. Cities located along the eastern coast of the delta (namely, Shenzhen and Dongguan) are characterized by relentless growth from 1992 to 2007, with a peak during the period 2000-2002. Foshan, Zhongshan, and Zhuhai, located on the western side of the coast, and Guangzhou, experienced an acceleration in urbanization from 2001, having a more even growth over time that decelerated in 2013. The cities more distant from the coast present the lowest percentage of urbanized landscape, as well as a more constant rate of growth.

Table 2: Urban land cover changes in the study area and variation, 1992-2015

City	1992 (ha)	2015 (ha)	Variation 1992-2015 (%)
Dongguan	7380	35451	380.37
Foshan	9324	34821	273.46
Guangzhou	10620	35856	237.63
Hong Kong	4716	6543	38.74
Huizhou	2088	11043	428.88
Jiangmen	2781	10737	286.08
Macao	261	621	137.93
Shenzhen	10638	25326	138.07
Zhaoqing	1206	5373	345.52
Zhongshan	2448	15543	534.93
Zhuhai	1125	4590	308.00
Pearl River Delta	52587	185904	253.18

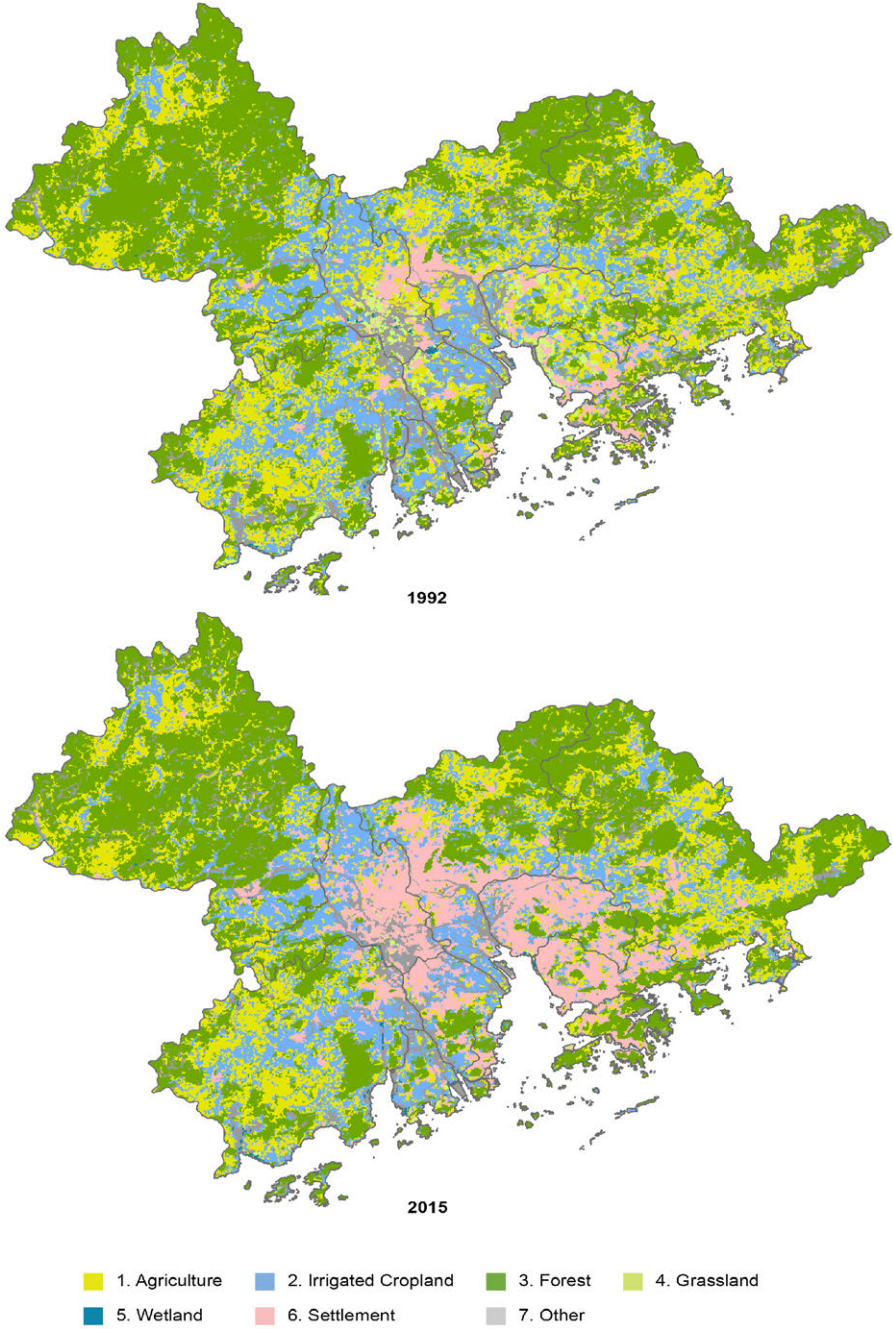


Fig. 1: Pearl River Delta, land cover maps for years 1992 and 2015

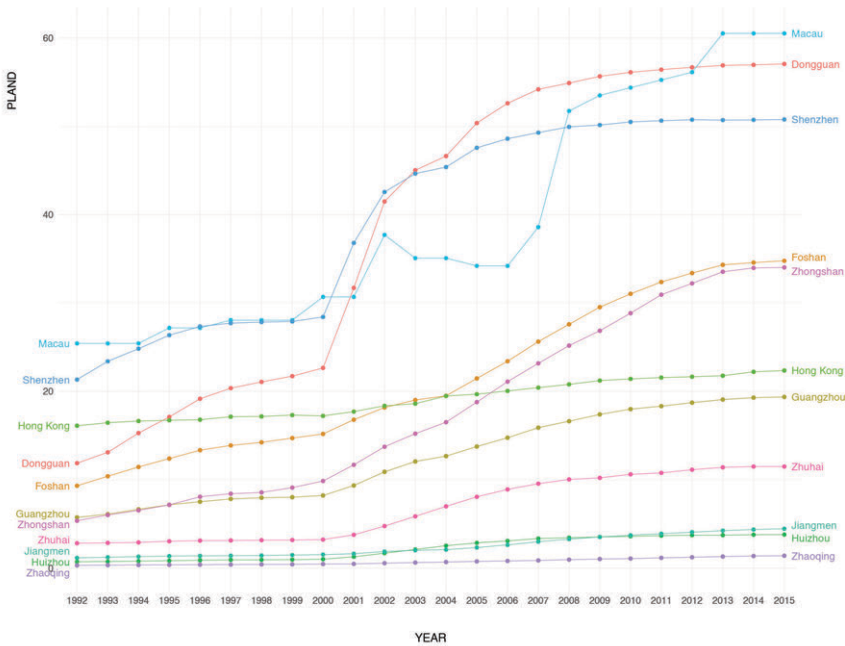


Fig. 2: Percentage of landscape (PLAND)

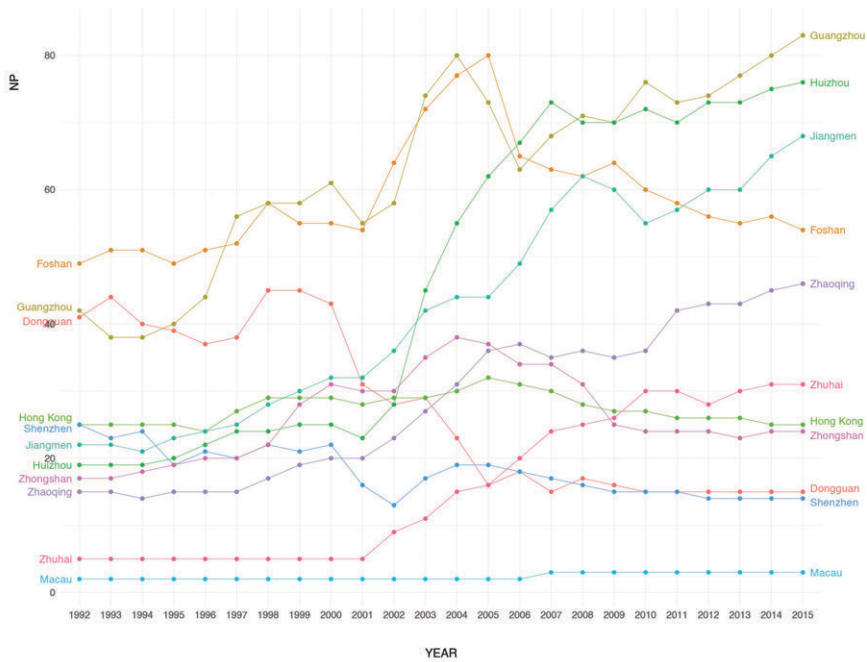


Fig. 3: Number of Patches (NP)

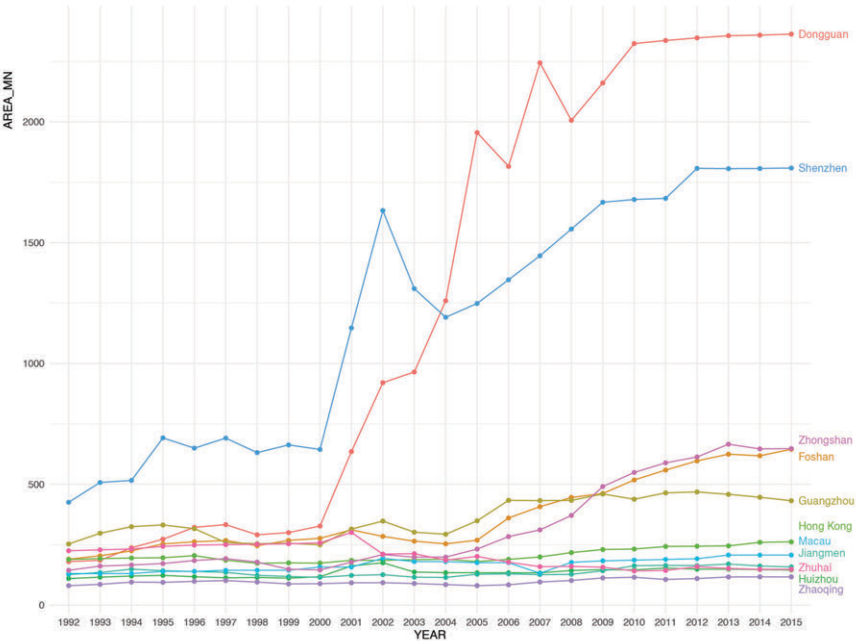


Fig. 4: Mean patch area (AREA_MN)

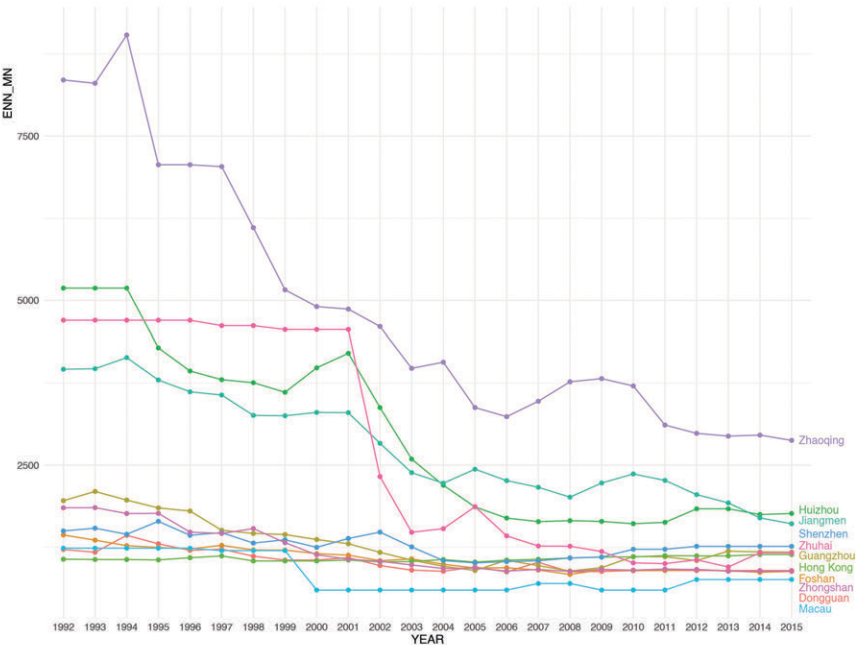


Fig. 5: Euclidean nearest neighbour distance (ENN_MN)

The Number of Patches (NP) index (Fig. 3) describes how fragmented the process of urbanization has been over time in various cities. In Dongguan and Shenzhen, the decreasing number of patches reveals a progressive merging of the urban areas, as well as in Foshan, where the number of urban patches declined from 80 in 2005 to 54 in 2015. Guangzhou, Huizhou and Jiangmen present the highest number of patches in 2015 (respectively, 83, 76 and 68). The AREA_MN index, when coupled with the Number of Patches, shows that in some cities the patch number increased and the AREA_MN index was stable, meaning that the land conversion happened in a scattered and fragmented manner. This is the case of Zhaoqing, Huizhou, Zhuhai and Jiangmen. Lastly, the declining trend of the Mean Euclidean Nearest-Neighbourhood Distance (ENN_MN) index shows that the built-up patches of the PRD's cities are consolidating all over the delta.

5 Discussion and Conclusion

The study shows that a mapping approach using landscape metrics to address dynamics of change is a valuable means to generate knowledge to support a better understanding of how a region has been developing over time. Maps are a very powerful means for spatial research, but often difficult to evaluate. Integrating and representing landscape metrics in mapping can help to gain extra insight in specific aspects by providing a measure of the magnitude of how urbanization processes take place, facilitating the interpretation of spatial patterns transformations by comparing the diverse temporal 'snapshots', and inspecting the divergences within a region. When coupled with maps, they can help discern not only where but also how much and with which pace transformation occurred, supporting the identification of those spatial opportunities and challenges that urbanized deltaic landscapes present, helping practitioners and decision-makers to better define strategies that can support the development of a region towards a more desirable future.

When explored and represented on a temporal perspective, simple metrics such as the total area (CA) and the proportion (PLAND) of urbanized areas offer the opportunity to describe the intensity of transformation (Fig. 5), whereas by investigating the variation of number of patches (NP), their mean area (AREA_MN) and calculating the Euclidean nearest neighbour distance (ENN_MN) is possible to get a grip on their level of fragmentation and isolation.

In this study, we analysed the land-use change over the period 1992-2015 on a yearly base using the ESA CCI land cover maps, focusing on the urbanization and comparing the 9 cities and the 2 SARs in the PRD. The analysis showed that the rate of urbanization in the area increased over the period 1992-2001 and then the trend decreased slowly in the period 2013-2015. A comparison of the cities showed the temporal patterns of urbanization were different among the distinct parts of the delta (the main cities, the eastern axis, the western axis, 'the peripheral' areas), both in terms of variation of extent and number of patches. Cities such as Guangdong and Shenzhen, which had earlier urbanization, tended to be more compact, whereas the more peripheral cities present an increasing number of urban patches.

The land cover maps provided by ESA CCI can be a valuable resource to use to perform temporal analysis, as they cover a wide timespan extending from 1992 to 2015, on an annual basis. However, some limitations are directly connected to the resolution with which such maps are elaborated, as the resolution of the maps proved not be sufficient enough for those cities having a smaller extent, such as Macao. Further investigation is needed to examine the

impact of urbanization on the different landscape classes, in particular on the agricultural areas and the irrigated and post-flooded croplands.

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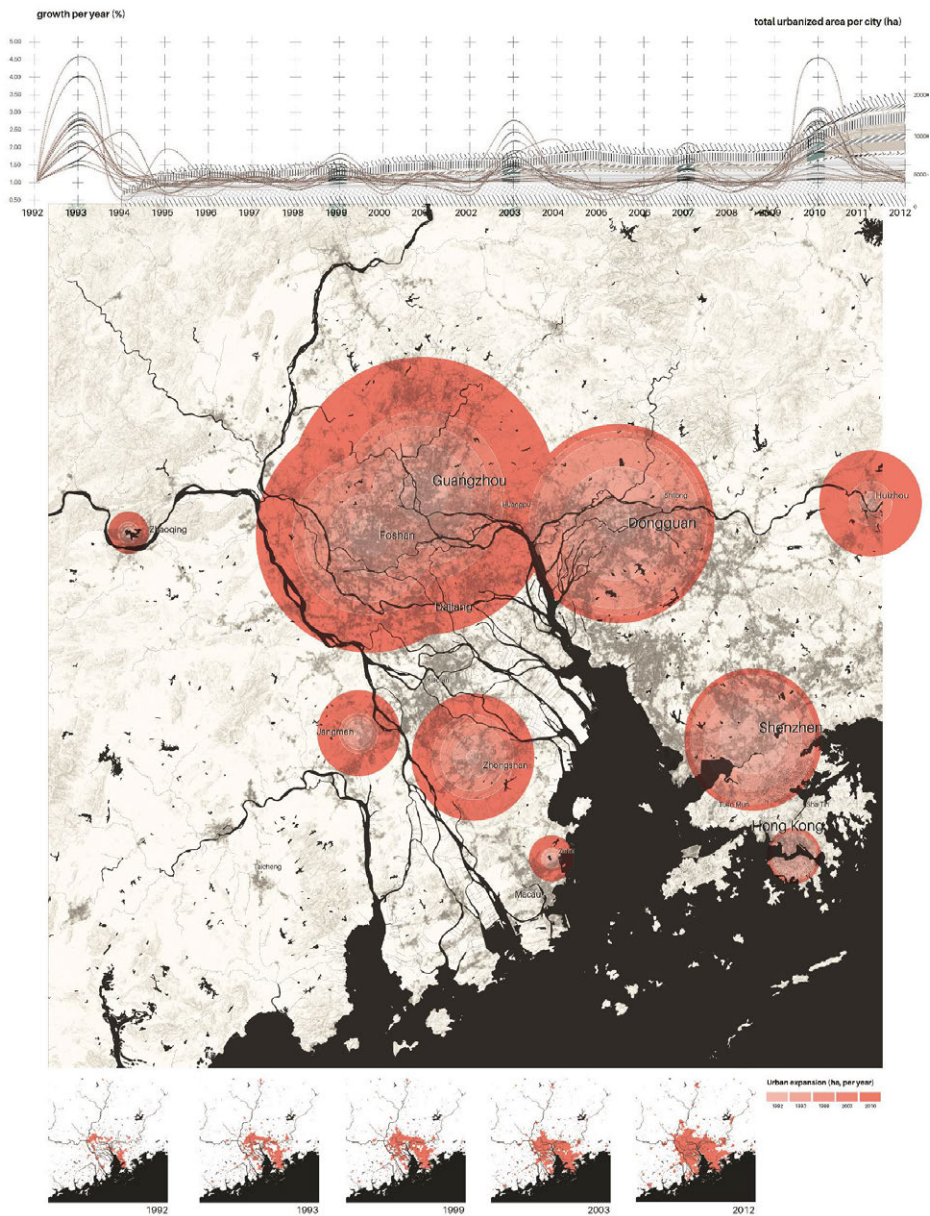


Fig. 6: Map of the urban growth of the PRD (years 1992, 1993, 1999, 2003, 2012)

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