Visualization and Communication of LUC Data

Francisco Escobar

Abstract

The increasing number of disciplines and public and private sectors interested in land use/land cover (LUC) information has boosted the demand for and the production of related cartographic products. However, the communicating power of the final maps may be impaired, if any of the cartographic transformations performed during the mapping process does not adapt well to the particular subject or area being mapped. This chapter takes the reader on a guided tour through the map production process, offering an overview of the cartographic language, the rules and practices that contribute to the success of the map as a communication tool and the most common forms in which LUC maps appear. Recent developments in geovisualization tools applied to LUC are also discussed.

Keywords

Cartography • Communication • Land Use Cover • Mapping

1 Introduction

The main purpose of cartography is to communicate geospatial information. The map serves as a channel through which a message is transmitted from the sender—the mapmaker—to the receiver—the map user (Robinson 1953, 1969; Muller 1975; Koláčny 1977; Ratajski 1978; Morrison 1976).

Like any other communication tool, cartography possesses its own language. The term "language" has been used by a number of authors in this field and can be defined as a system of signs enabling communication (Cauvin et al. 2010a). For communication to be successful, these signs should be capable of conveying to the reader the concepts that the author wishes to transmit. Given that maps also seek to convey information through signs, cartography must be considered part of semiotics. Indeed, as early as 1952, Robinson developed this idea by introducing a whole system of specific symbols for mapmaking (Robinson 1952).

Subsequently, various studies explored this concept in greater depth, culminating in 1967 with the seminal piece by Jacques Bertin "Semiology of Graphics", a genuine world reference on this subject. This was followed in 1978 by Ratajski, who outlined that, in modern thematic cartography, the ultimate goal of semiotics is to build an accurate, unambiguous cartographic language.

In cartography, semiotics unfolds as two different categories of signs; on the one hand it refers to **geometric signs**, the spatial dimensions (zero, one, two or three) and the geometric nature of map features (points, lines, polygons and volumes), and on the other, to **visual variables**, defined as the possible elementary variations in perceptible marks (Bertin 1967). This definition was frequently cited, and eventually revised, by other cartographers (Cauvin et al. 2010a; Robinson 1953; Robinson et al. 1984; Monmonier 1993; Slocum et al. 2005).

In this chapter we will be focusing on both kinds of signs and their role in the cartographic representation of land use/land cover (LUC).

Recent technological advances in the GIS industry have popularized cartography, giving rise to what some people refer to as a "geospatial society" in which maps are increasingly ubiquitous and used in all kinds of applications. This has brought new opportunities for cartography as a science but it also poses new challenges, one of which is that many new mapmakers lack the necessary cartographic skills to produce effective maps. Unfortunately, there are numerous examples in the literature that illustrate the fact that GIS has made it easy to produce large numbers of wrong or

F. Escobar (✉)
Departamento de Geología, Geografía y Medio Ambiente, Universidad de Alcalá, Alcalá de Henares, Spain
e-mail: francisco.escobar@uah.es

D. García-Álvarez et al. (eds.), *Land Use Cover Datasets and Validation Tools*,
https://doi.org/10.1007/978-3-030-90998-7_5

confusing maps more quickly than ever before. In the case of LUC mapping, no matter how sophisticated and expensive the technology for the collection and processing of the information may be, inexpert mapmakers often fail to communicate the relevant information correctly.

In order to help overcome these issues, this chapter aims to provide the basic ground rules for the correct representation and interpretation of LUC maps.

2 Geometric Signs

The geographic entities we find in the landscape are portrayed on maps as cartographic objects of varying geometric nature. Different land use areas are no exception and are usually depicted as polygons. The process for representing this information on a 2-dimensional piece of paper or on a screen is anything but simple as it involves, at least, the following transformations; (1) projecting the irregular and curved surface of the Earth on a plane, (2) selecting land use patches of sufficient size as to be visible (and readable) on the map, and (3) aggregating the information at the right administrative level when analysing LUC distribution over statistical spatial units. These three transformations have important implications for LUC mapping, which we will now go on to explain.

2.1 Cartographic Projection and LUC Mapping

The representation of our curved planet on a 2-dimensional map requires the application of mathematical models, known as cartographic or mapping projections, to project the Earth's surface on a plane (Slocum et al. 2005). Deformations occur during the projection process, which provide differentiating criteria to enable us to classify these projections into three big families; conformal, equidistant and equivalent, the last of which is also referred to as equal area.

- Conformal projections are used in navigation charts, as their main characteristic is the preservation of angles. Parallels and meridians intersect in a perpendicular manner, so forming four 90º angles at each intersection and an orthogonal network as a whole. However, these maps show important distortions in terms of the proportionality of areas and distances.
- Equidistant projections preserve the distances between specific pairs of points and distort areas and angles. These kinds of projections are mainly used in engineering and construction works.
- Equivalent or equal area projections preserve the proportionality of areas and by doing so distort the shapes and distances.

The bigger the area represented, the greater the impact of our choice of projection. This is noticeable in world maps where familiarity with the shapes of countries and continents make it easy for the reader to understand the deformations in each case. However, in smaller areas whose shape is not usually familiar to the general population, the map reader will find it difficult to notice the deformations. Of course, given the limited portion of the Earth's surface portrayed, the effects of the deformations are not as obvious as in world maps, but they do exist and can have an impact on LUC mapping. Since the choice of the projection results in significantly different maps, as Fig. 1 shows, the mapmaker must decide which projection system suits their map best. A bad choice could result not only in an unwanted distorted map, but also in a map that estimates metrics incorrectly. LUC analysts want metrics that inform the reader about different aspects of LUC, among them land use category distribution patterns and clusters, and especially the size of individual or groups of patches. This means that LUC maps must preserve the proportionality of areas. Conformal and equidistant projections are unsuitable for this purpose and equivalent projections must therefore be used.

2.2 The Minimum Mapping Unit in LUC Maps

The minimum mapping unit, or MMU, defines the size of the smallest cartographic object that will appear on the map (Cauvin et al. 2010a), in this way determining the resolution and by extension the most appropriate scale for the map.

Today, the predominance of digital maps over paper-based maps and their capacity to zoom in and out mean that the MMU is not as obvious as in the past. However, all maps are affected by the mapmaker's choices regarding their final scale, and the MMU has to be set in such a way as to facilitate the useability and readability of the map. In digital maps, the zoom feature may incorporate 'intelligent' functions, which allow it to display certain map elements, features and labels, solely at the appropriate level of zoom. The result is that when the user zooms out, the smaller features are hidden and when they zoom in again, more and more small features become visible. For the intelligent zoom to work properly, the mapmaker must establish a different MMU at each zoom level, in this way deciding which elements will be visible at each different scale, an important decision in the mapmaking process.

CORINE Land Cover is a well-known European project, which established an MMU of 25 hectares for areal entities and a minimum width of 100 m for linear features (European Environment Agency 2017). This means that in a printed map at the recommended working scale of 1:100,000 the MMU will occupy 0.5 cm^2 or 25 mm^2.

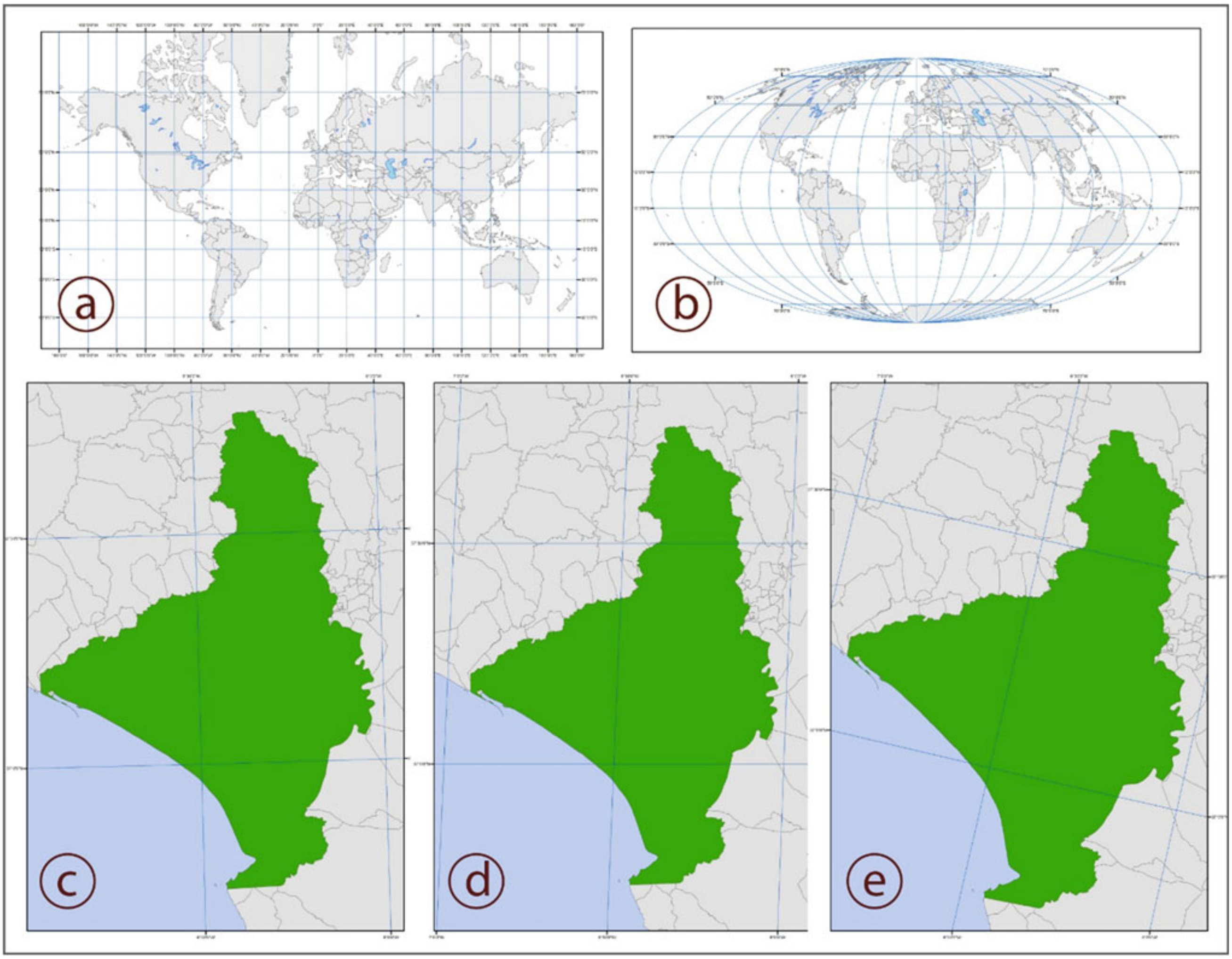

Fig. 1 Impact of the cartographic projection on map appearance at global and local (Guadiamar River Basin) scales. **a** Mercator projection (conformal), **b** Mollweide projection (equal area), **c** ETRS89 / UTM zone 29N (conformal), **d** Mollweide (equal area), **e** Europe Equidistant Conic (equidistant). For demonstration purposes only, the differences between (**d**) and (**e**) have been accentuated by applying a World and a European projection system respectively

The MMU also plays an important role in the data collection phase. Regardless of whether data is collected by field work or by interpretation of aerial or satellite imagery, the features that are smaller than the MMU will not appear on the map.

Some authors work almost exclusively with raster structures for which the pixel is the basic unit. As a result, they tend to conceive the MMU in terms of pixel size. From this perspective, it is generally accepted that the smallest observable feature in the final map, i.e. the MMU, should comprise at least four contiguous pixels (NOAA 2011).

When it comes to determining the MMU of LUC maps, it is important to differentiate between databases and maps. Patches that might be a suitable size for data analysis could be completely inappropriate for map publishing. Single pixels or small groups of pixels forming small areas below the MMU threshold might be considered in data analysis, but would not appear on the map.

Three intrinsic characteristics of LUC mapping must be taken into consideration when deciding the most appropriate MMU: (i) Confusion between use and coverage, (ii) Definition of land use categories and associated land size, and (iii) High sensitivity of LUC maps to the interrelations between MMU and scale. The scale at which LUC information is expressed also has an enormous impact on the communication capacity of the resulting map (Wu and Harbin 2006; García-Álvarez et al. 2019).

In what is a common confusion between land use and land cover, different MMUs can result in maps showing different categories. For instance, at a relatively coarse resolution, a MMU of 1 km^2 would lead to an airport being depicted as such in both a land use map and a land cover map. However, if we increase the resolution by reducing the MMU to 50 m, the land use map would still depict it as an airport, but the land cover map would classify the areas covered by runways, buildings, or green areas into different categories.

The second characteristic of LUC information that affects the MMU is directly related to the first. The increasing availability of Earth observation products with greater spatial resolution could lead to the false idea that the higher the resolution of the images, the better the quality of the data obtained from them. However, land use, i.e. the "arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it" (Di Gregorio and Jansen 2000) cannot be observed in areas smaller than that required to carry out said activities and arrangements. For instance, the MMU for a LUC map category representing low-density residential development must be at least as small as the basic unit (house with garden) for this kind of land use.

The third intrinsic characteristic of LUC information that impacts on the MMU is its nature as a covering phenomenon. Mapping LUC information involves the delimitation of areas showing homogeneous coverage. This poses a problem in the data collection phase of small-scale LUC maps, in which the MMU covers a significantly large area that probably includes several LUC categories. In these cases, the identification of homogenous areas becomes a much more complex task. In order to assign a single value to the area in question, the cartographer must apply one of the available criteria. The most frequently used criteria include allocating the area: (i) to the LUC category covering the largest proportion of the area or (ii) to the predominant LUC category in the surrounding area. Related issues arise when attempting to downscale or upscale previously existing geospatial information. This increases the uncertainty of the map (García-Álvarez et al. 2019) and could give rise to the Modifiable Areal Unit Problem (MAUP) and the Category Aggregation Problem (CAP).

2.3 The Modifiable Areal Unit Problem (MAUP) and the Category Aggregation Problem (CAP)

LUC can be mapped and conceptualized in different ways; from the most typical LUC maps in which the areas are classified into homogeneous categories, to choropleth maps which summarize, at selected administrative levels, different statistical values for the LUC they contain. In all cases, LUC information is expressed via polygon-based geometry but the MAUP is most noticeable in choropleth maps.

The MAUP was analysed in depth by Openshaw and Taylor (1979) and its effects have been tested in a number of research studies (García-Álvarez et al. 2019; Cebrecos et al. 2018; Rajabifard et al. 2000). The MAUP appears when a specific variable is observed in spatial units of different levels within a hierarchical structure (Eagleson et al. 2002, 2003). The MAUP causes two effects—zoning and scale. The first refers to the different patterns and associated statistical measures resulting from different aggregation arrangements within the same hierarchical level. The second takes the form of new and different patterns of the analysed variable that appear when downscaling, i.e. when units are aggregated together to make larger units.

LUC mapmakers and users need to be aware of the impact of the MAUP in order to facilitate both successful communication and well-informed decision-making.

Another issue in relation to the downscaling of information is the Category Aggregation Problem (CAP), which was formulated more recently (Pontius and Malizia 2004). This problem refers to the important consequences of grouping the categories in a thematic legend together. This leads to the disappearance of certain subcategories from the legend, so complicating the analysis of the changes in these variables over time (García-Álvarez 2018). The aggregation of categories also reduces the level of detail offered by the map.

In LUC these constraints are key aspects in the correct production and analysis of related maps. Figure 2 illustrates some of these issues. At the scale used in these maps, the progressive categorical aggregation from left to right shows the need for larger MMUs. The most categorically detailed map is very difficult to read, while the most generalized map provides insufficient information. Setting the MMU therefore entails a trade-off between the scale, the level of analysis sought, and the number of categories. This means that both components (thematic and spatial) of the geographic information must be considered simultaneously when setting the MMU in LUC mapping.

3 Visual Variables

The expression 'visual variable' was used by J. Bertin (1967) to designate the components of a system of signs. Later on, Slocum et al. (2005) defined it as the variations and perceived differences in the signs used to represent a thematic phenomenon. Other terms adopted by cartographers when referring to visual variables are symbol, graphical variable, graphical primitive or mark. Bertin identified six visual variables: shape, orientation, colour, value, grain and size, which have since formed the basis of studies of cartographic semiotics (Slocum et al. 2005).

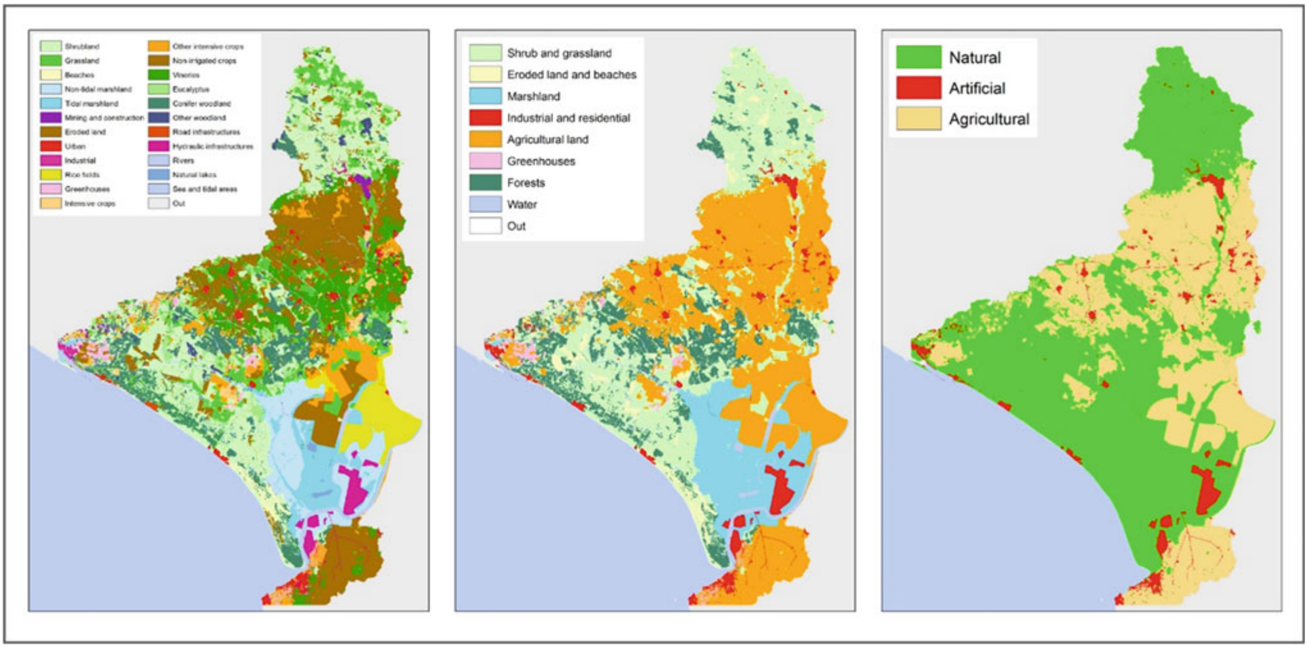

Fig. 2 Examples of LUC map information and issues arising from changes in the MMU and the aggregation of categories

3.1 Shape

Shape is the first variation distinguishable on any map. It helps identify the different types of objects appearing on a map, which are described by different contours. These contours may be regular and abstract (geometric signs) or figurative (pictograms). Shape corresponds to a nominal level of measurement and only allows us to convey either associations between objects with the same shape or differences between elements represented by different shapes. Shape is neither ordinal nor quantitative and cannot therefore be used for thematic phenomena with ordinal or quantitative levels of measurement (Cauvin et al. 2010a).

In LUC mapping as in any other kind of polygon-based mapping, shape can only affect filling patterns, not the shape of the polygons themselves. The only exception to this rule are cartograms, in which both the size and the shape of polygon objects vary in line with quantitative thematic values. In maps showing point and line features, shape is frequently used to highlight different associations between categorical objects.

3.2 Orientation

The orientation of a sign refers to its position relative to a reference framework and it is expressed in degrees (between 0 and 360). As with shape, orientation can only represent the attributes on a nominal level of measurement and can only affect point-based elements (Cauvin et al. 2010a). For line, polygon or volume geometries, the orientation would only affect the filling patterns (textures) chosen. It is used much less frequently than other visual variables, especially in LUC mapping.

3.3 Colour Hue

Colour hue (often referred to simply as colour) is the most complex visual variable and its use in maps has been extensively analysed by cartographers (Bertin 1967; Robinson et al. 1984; Monmonier 1993; Slocum et al. 2005; Cauvin et al. 2010a). Colour varies depending on the light source, the reflective characteristics of the observed object and the human eye. The visible world is in fact composed of colourless matter but electromagnetic waves with different wavelengths are perceived as different colours by most people.

As a visual variable on a map, unlike shape and orientation, colour can be used not only in points, but also in lines and polygons. As regards its properties in relation to thematic information, colour is selective, separative and associative. Colour hues are neither ordered nor quantitative, which means they cannot be used to represent attributes measured at quantitative scales, and are therefore only suitable for representing phenomena measured at nominal scales. However, under certain conditions and when arranged in the appropriate order, colours can also be used to express order and opposition. For instance, yellow, orange and red can represent low, medium, and high data values, respectively (White 2017).

In addition to Bertin's pioneer work and the revisions to his visual variables made by subsequent authors, a milestone in the application of colour hue schemes in digital mapping is the ColorBrewer Tool developed by Cynthia Brewer at Penn State University (Brewer 2021). The ColorBrewer tool offers an extensive collection of colour ramps, which are well-suited for any measure of scale and for colour-blind map users. In terms of LUC mapping, an interesting proposal for colouring LUC maps with coarse pixel data can be found in Raposo et al. (2016).

The use of colour in mapping is also affected by its cultural connotations. As pointed out by Hall (1971), signs and gestures have different, sometimes even contradictory meanings depending on the cultural background. One example is the connotations associated with red, as danger, versus green, as safety in western cultures.

In addition to these cultural constraints, for map communication to be successful, the use of colour in mapping must honour some generally accepted conventionalisms. In LUC mapping, for instance, water bodies are always represented in light blue, while residential areas are normally depicted in red.

A very useful, well-known colour scheme for LUC mapping was established by the European Environmental Agency in the Corine Land Cover project (EEA 2017). Its 44 categories are represented by colours whose different hues are assigned to different groups of categories. In this way, artificial areas are represented in reds and purples, agricultural uses in yellow, forests in green, open spaces in grey and green, and wetlands and water bodies in blue.

3.4 Colour Value

White (2017) defined colour value as the lightness or darkness of a colour from pure black to pure white. Its variation constitutes "a continuous progression which the eye perceives in the grayscale stretching from black to white" (Bertin 1967) in a given area. Cauvin et al. (2010a) noted that the term progression conveys the basic property of this visual variable—order. It can be expressed as the ratio of the respective quantities of black and white.

As this is an excellent way of expressing order, it highlights the differences in a hierarchical system. Even though it is frequently used to represent quantities, the human capacity to associate different colour values with different quantities is very limited. Today, however, digital mapping allows black to be allocated in amounts that vary in proportion with the thematic value, so making it possible to use value ramps that overcome this limitation.

Like colour hue, colour value can be used in all geometric forms, although the best results are obtained on an area or volume, as the map user requires a certain minimum amount of surface area to perceive the variations of grey.

Since colour value is not suitable for representing nominal data, in LUC maps it is only used to summarize quantitative variables related to land use within administrative areas.

3.5 Texture

Texture or pattern is a complex visual variable that comprises a varying number of components depending on the author you consult. According to White (2017), textures combine size, value, hue, shape and orientation. Other authors reduce these components to shape, arrangement, grain and spacing. Shape is the basic graphic unit making up texture. Arrangement refers to the layout of the basic graphic elements, either regular or irregular. Grain refers to the size of these elements and spacing to the distance between them. The use of textures for data measured at different levels is also controversial. While White recommends that textures only be used for nominal and ordered attributes of areas and lines, other authors (Cauvin et al. 2010a) claim that they can also be used for quantitative data.

Nowadays, textures are not used as often in mapping as they once were. In the past, when colour printing was significantly more expensive, textures were frequently used to fill out areas containing nominal, ordinal or quantitative information. Today textures have largely been replaced by colour. However, they are sometimes used in combination with other covering visual variables such as colour hue or colour value, so as to increase the amount of information provided by the map.

Textures can be useful in LUC mapping when the basic LUC information is combined with other relevant information. In the case shown in Fig. 3, the area occupied by the Sierra de Guadarrama National Park in Spain has been texturized to differentiate it from the rest of the mapped area.

3.6 Size

Size is, together with colour value, the most frequently used visual variable for representing quantitative data. Size can be defined as the variation in the area or the volume of a sign. It is rarely used in LUC mapping as these maps are normally based on categorical data. Although in theory, size expresses quantity, order and selection (Bertin 1967), its use in representing qualitative information can lead to confusion.

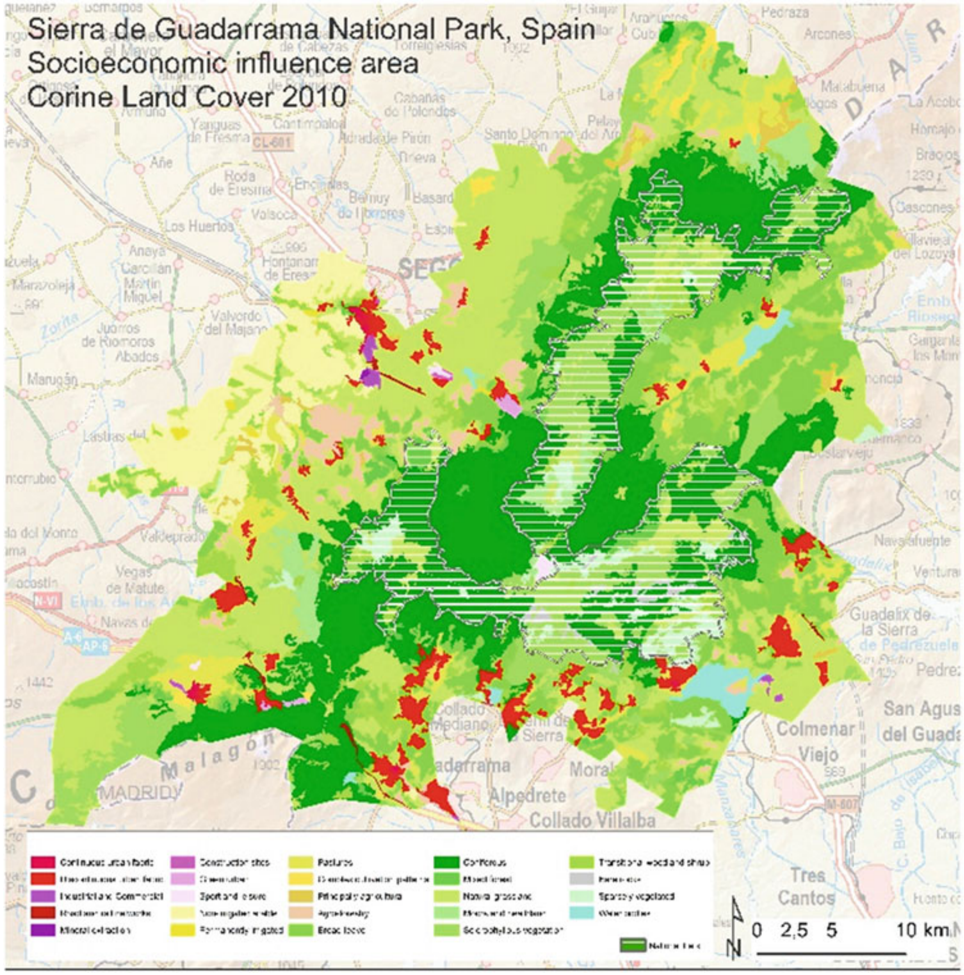

Fig. 3 Use of textures in LUC mapping

Thus, size is only recommended for representing ordinal or quantitative data.

As regards the geometries of the map, size can only be fully applied to points. In the case of lines, since the distance between two points is fixed, size can only be applied as a variation in line width. As for polygons, any variation in their size based on a quantitative attribute other than surface area would result in the loss of their cartographic projection properties. Given this constraint, when the nature of the attribute is such that its representation with size is recommended, polygons may be represented by a point, usually at their centroid, which varies in size according to the value attached to the polygon attribute.

LUC map products using this visual variable are therefore limited to those summarising quantities such as the proportion of land occupied by each land use category, the proportion of land undergoing a land use change between two dates, or other related quantitative variables. In all cases, these quantities are summarized on a superimposed spatial structure, usually administrative units.

3.7 Visual Variables and Geometric Dimension

In the previous paragraphs, we have seen how some visual variables adapt better than others to the varying geometric forms in which geographical information is presented.

Figure 4 summarizes the recommended use of the visual variables with different geometries. Green cells show optimal combinations, red cells show inapplicable combinations and yellow cells show the combinations that are subject to certain conditions. Points accept all visual variables with the exception of textures, although some points may be big enough to accommodate texture pattern. Given that lines are defined as the shortest distance between two points, they can only accept colour hue and colour value. However, a thick line can have different shapes and textures. As regards size, according to the above definition, lines can only vary in width, not in length. Polygons are more restrictive, in that they will only accept colour hue, colour value and texture. Any change in their shape, orientation or size would result in a distortion of the cartographic base which makes them

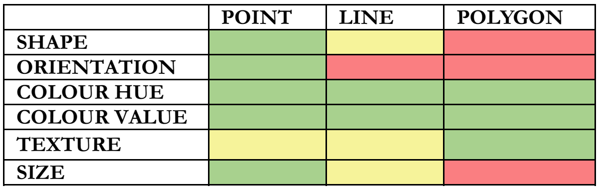

Fig. 4 Visual variables and geometric dimension

unusable. However, these three visual variables could be applied to polygons when they (the visual variables) form part of the texture pattern that fills these polygons.

3.8 Visual Variables and Measurement Level

In the above descriptions of the visual variables, we also outlined the meanings with which they are associated, and consequently the most suitable level of measurement for them. In general terms, the visual variables that can be ordered (colour value, size, texture and colour hue if properly ordered) are best suited for attributes measured at ordinal level. Visual variables indicating quantity (size and to some extent colour value and texture) can be applied to represent attributes at interval or ratio measurement levels. For their part, the visual variables with selective and associative properties, such as colour hue, shape and orientation, are used to represent attributes measured at nominal level.

Orientation is a special case. It usually has the same meaning as shape, but under certain conditions it can also be used to represent ordered attribute series. For instance, an arrow symbol pointed at any angle in the 360° of a circle could be associated with an ordered attribute depicting every point in a hierarchy based on the angle of the arrow.

As regards textures, their complex nature makes them suitable for any measurement level. Changes in the shape, orientation and colour hue of the pattern of elements that make up the texture would apply to attributes at nominal scale while size and colour value variations would be used to represent attributes at quantitative and ordinal measurement scales. Figure 5 summarises the recommended application of visual variables to represent attributes with different measurement levels.

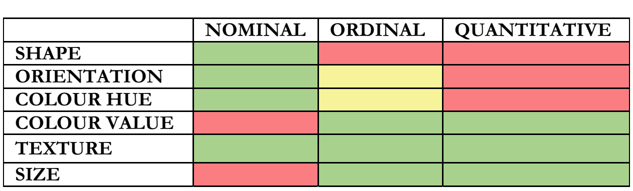

Fig. 5 Visual variables and associated level of measurement

4 Representing Nominal LUC Data

Most common LUC maps depict an area or region, highlighting with different colours the homogeneous patches of the different LUC categories it contains. As described above, for these maps to serve as successful communication tools, they must comply with a series of cartographic rules.

In terms of cartographic projection, the proportionality of areas must be preserved. If not, it would be impossible to compare the respective size of the different categories on the map. Equivalent projection must therefore be used.

The final size of the map will determine the scale and therefore the size of the Minimum Mapping Unit. In the case of digital maps, we recommend that an intelligent zoom be used so that the map only displays features equal to or greater than the minimum size. As a fixed image, the final LUC map must also strike a balance between the MMU and the number of LUC categories.

The visual variable best suited for categorical data is colour hue. Its use in LUC mapping must adhere to generally accepted conventions such as the use of blue colours to represent water bodies, reds and purples for built-up areas and so on.

In line with these recommendations, Fig. 6 presents an example LUC map for the Guadiamar River Basin area in Southwest Spain based on Corine Land Cover data for the year 2000.

5 Representing LUC Quantitative Data

As pointed out above, the cartographic representation of LUC quantitative data requires additional layers, such as administrative units, for the computation of these quantities at a meaningful spatial level. Some sort of selection must be undertaken in order for the resulting maps to be readable. Figure 7 shows examples of the percentage of land occupied by natural, agricultural and artificial land use categories respectively.

As with any map representing quantitative attributes, special attention must be paid to the number of intervals and their limits. An excessive number of intervals would make it difficult to differentiate between the associated symbols, regardless of whether they are based on size or colour value. By contrast, if too few intervals are used, this will reduce the level of detail of the information provided by the map. Brooks and Carruthers (1953) suggested that the number of classes should be less than or equal to five times the decimal logarithm of the number of observations. Other authors suggested that the number of classes should be equal to 3.3 times the decimal logarithm of the number of observations plus 1 (Huntsberger 1961). In both cases the number

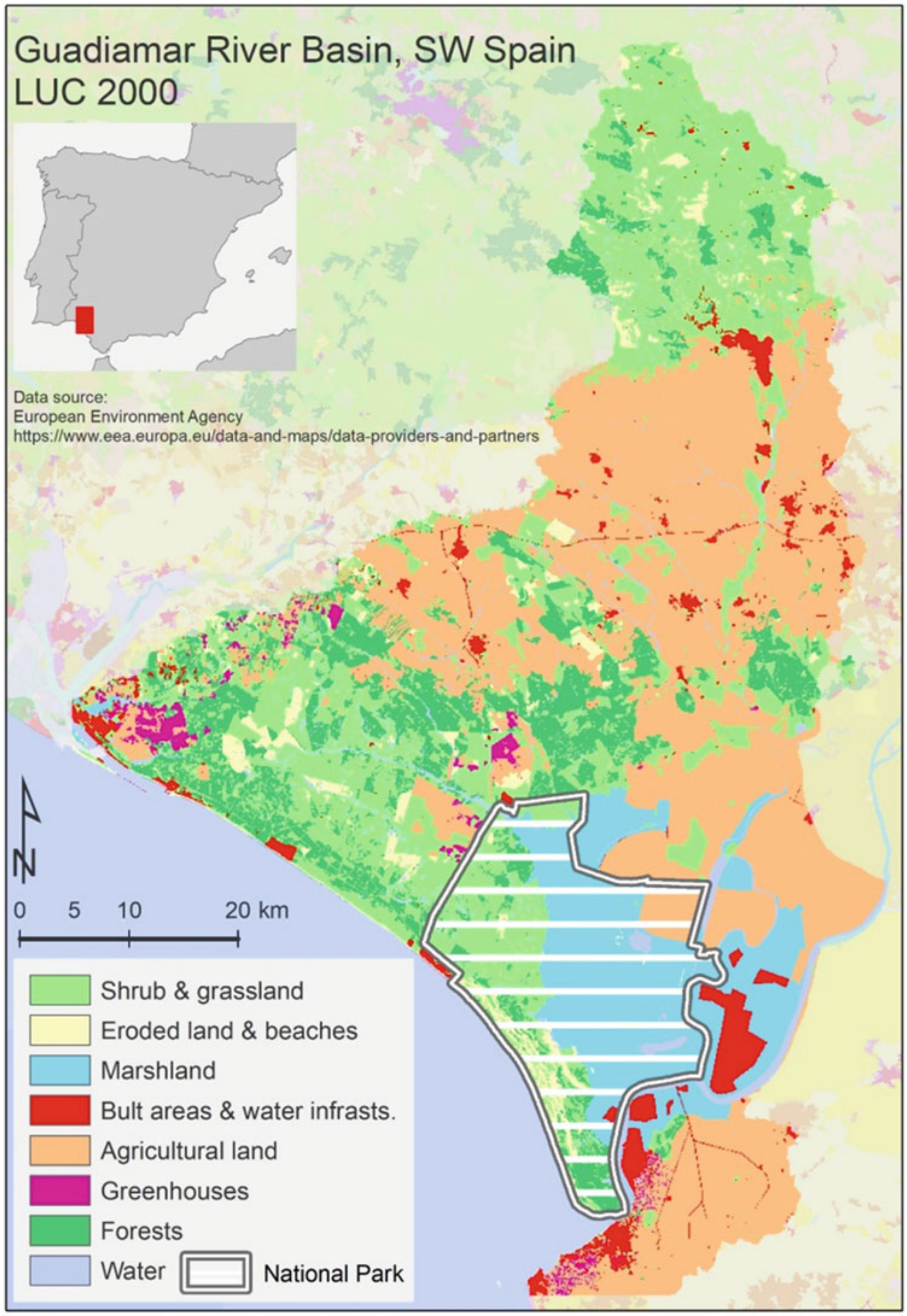

Fig. 6 Example of LUC map. Guadiamar River Basin, Spain

of classes increases quickly in line with the number of observations, making it difficult for the map reader to differentiate between the symbols. The average maximum number of different colour values that humans can perceive in a map is seven (Olson 1975) and, according to Robinson (1998), the optimum number is five.

The limits established for each of the intervals have a strong impact on the final appearance and usefulness of the map. There are a large number of possible methods for establishing these limits, but not all of them adapt to all sorts of data. The distribution of the thematic variable must be taken into account, as some methods are only suited to

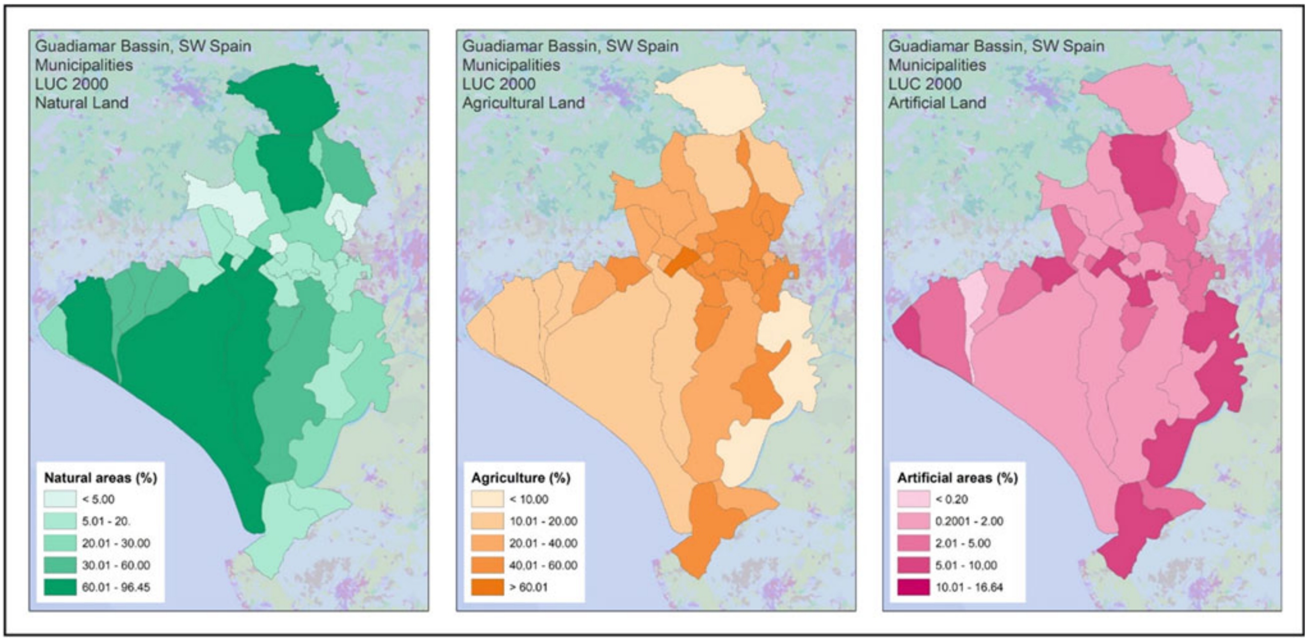

Fig. 7 Quantitative maps showing the area occupied by different land use categories in the Guadiamar River Basin

certain specific distributions. Following work by Monmonier (1982), Cauvin et al. (2010b) explained the details of the various different methods and analysed their advantages and disadvantages. In this chapter, we will be focusing on the main methods available in standard GIS software. The varying impact of three of the most common methods can be seen in Fig. 8.

6 Representing Qualitative and Quantitative LUC Data

Pie charts enable the simultaneous communication of qualitative and quantitative LUC data. The pie symbol can display variations in colour hue, colour value, size and texture. It can

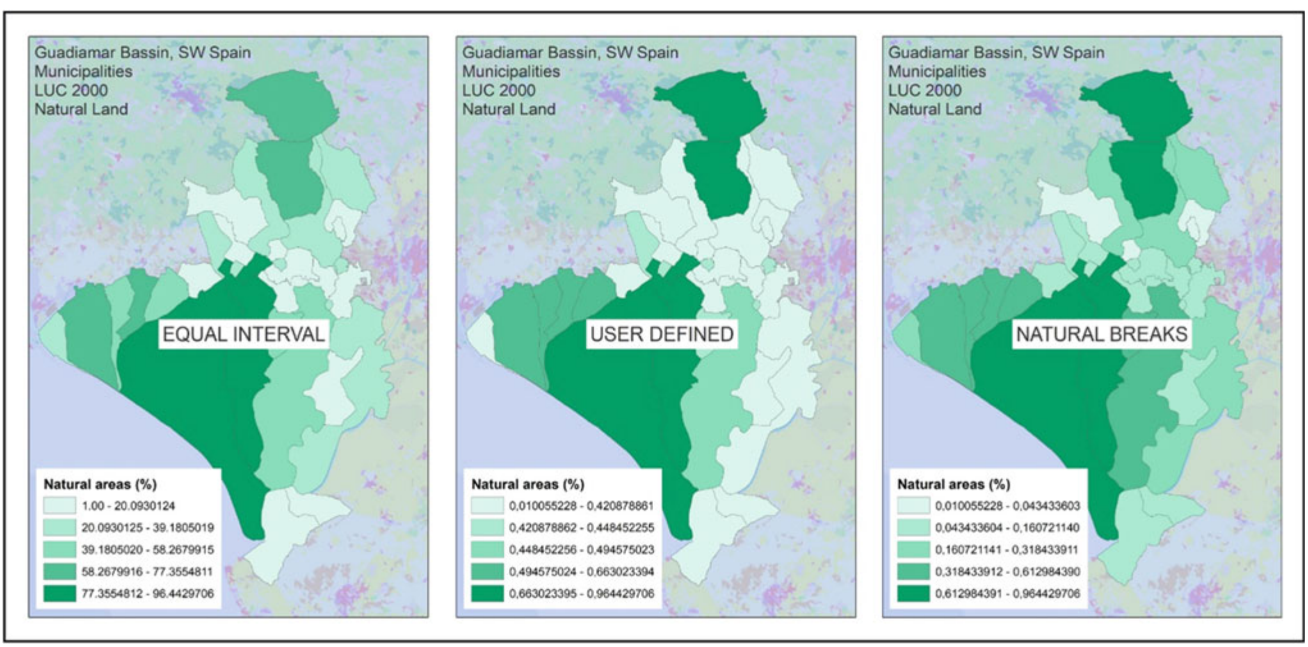

Fig. 8 Impact of the classification method in quantitative maps

represent nominal data by means of colour hue variations, while ordinal and quantitative data can be represented with size or colour value. Figure 9 shows the land occupied by natural, artificial and agricultural uses in the municipalities in the Guadiamar River Basin. Symbol size is proportional to the total area of the municipalities and the pie sections correspond to each of the categories coloured with a different hue.

7 Representing LUC Changes

One of the key areas in LUC studies is the analysis of the cover changes that have taken place in the past or are predicted to occur in the future, according to different scenarios (White and Engelen 1993; Camacho Olmedo et al. 2018; Hewitt et al. 2014; Guzman et al. 2020). The methods

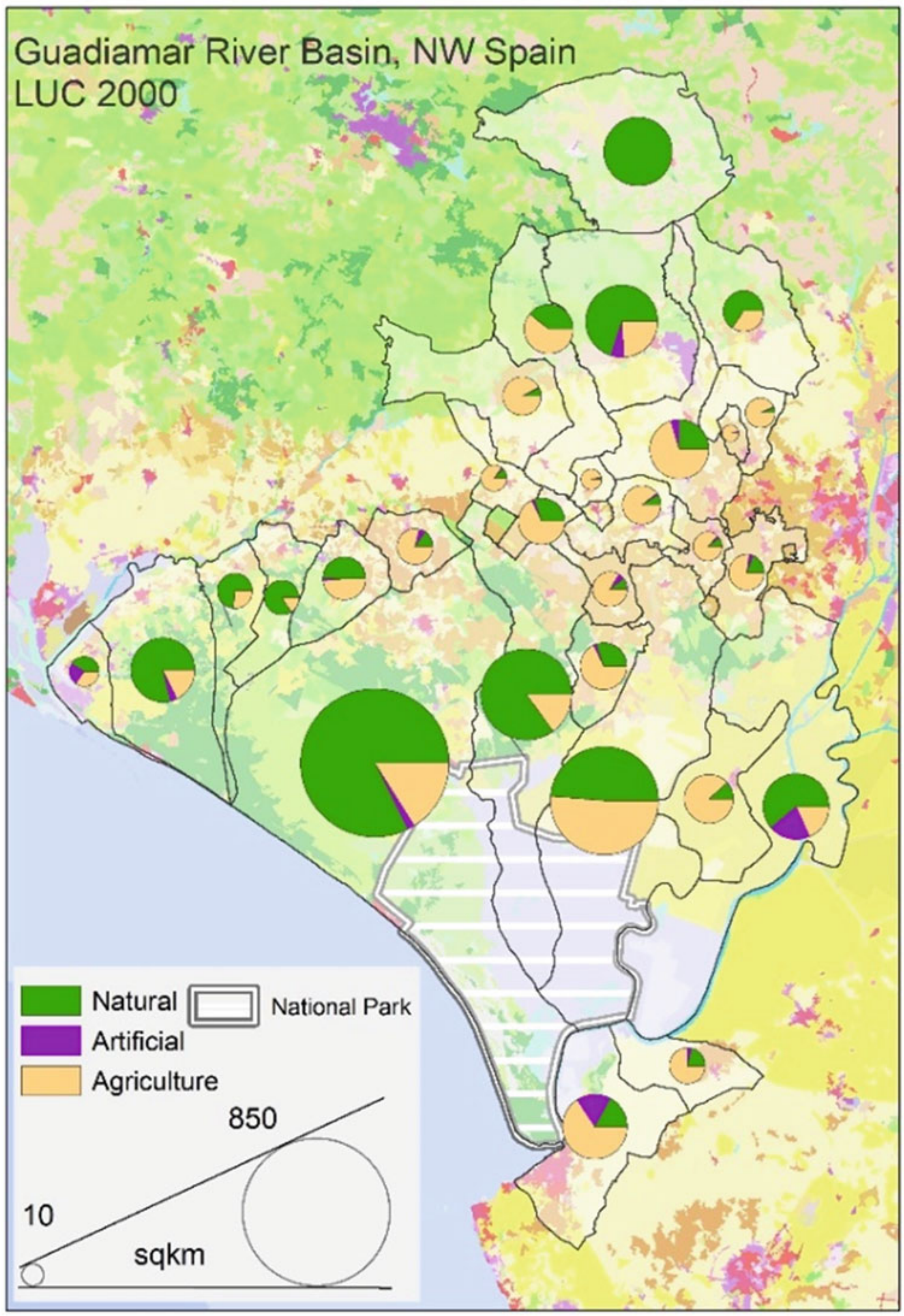

Fig. 9 Pie chart map representing the proportions of LUC categories in the municipalities in the Guadiamar River Basin

applied to undertake this analysis are usually based on the comparison of two input LUC maps with different dates.

The cartographic representation of the LUC change that has taken place between these two dates is often expressed in terms of the amount of land gained or lost by each land use category. This is a quantitative attribute and is therefore subject to the constraints summarized in Sect. 5.

As regards the representation of categories as nominal data, an excessively large number of land use categories in the input maps and their associated, theoretically possible transitions would in turn result in an excessively large number of new categories. This means that some kind of selection process must be performed. The options include: (i) reducing the map to the binary categories of "stable" and "changed"; (ii) selecting just one land use category to represent the areas gained or lost by it; and (iii) selecting the areas gained or lost by one specific land use category, in order to represent the land use categories from which or to which these areas have changed.

In order to make the comparison, the two input maps must be overlaid. During this process, it is highly likely that new areas of varying size will appear on the output map. The issues relating to the MMU discussed in Sect. 2.2. apply to the representation or possible generalization of these new polygons. Figure 10 presents a composite of two input maps with LUC information for 1956 and 1999 respectively, an output map showing areas that have undergone LUC changes between these dates and a second output map showing the main transitions that have taken place between LUC categories.

8 New Forms of Visualizing and Communicating LUC Data

Throughout the examples presented so far, we have made clear that LUC representation is a far from simple task and that LUC maps convey even the most relevant aspects of LUC information with difficulty. These limitations can have serious consequences when it comes to taking policy and land planning decisions. The abstract representation, normally by means of colour hues, of land use categories or the transitions between them does not necessarily make it easier for users to understand the real landscape changes they represent. Policy makers may not be expert map users, and will therefore require more intuitive information in order to fully comprehend the impacts of predicted land use changes on landscapes, economy, society and the environment. Van Lammeren et al. (2010) found that users complained about an excessive amount of detail on A4-size printed maps, that the colours were too close, and that it was difficult to compare the maps.

In an attempt to alleviate these issues, various interesting case studies have integrated new approaches to cartographic visualization (Cauvin et al. 2010c) such as realistic 3D models (Appleton et al. 2002; Paar 2006; van Lammeren et al. 2010), and have explored the use of historic photography to illustrate land use changes (Kull 2005).

In addition to these realistic 3D examples, technological developments in the mapping industry have enabled the production of new cartographic tools that have yet to be explored in the communication of LUC information. Three areas are in need of further research and implementation. First, the current predominance of digital maps that are viewed through a computer device equipped with speakers, contrasts with the almost complete absence of research into sound mapping applied to LUC analysis. Second, the limited interactive capacity of LUC digital maps makes it difficult to compare them. And third, the possibilities offered by the computerised environment for visualizing animations, perhaps the most efficient tool for communicating changes over time, have yet to be applied in LUC change studies.

9 Conclusions

In this chapter we have reviewed the main cartographic methods for representing and communicating LUC and LUCC information. The maps produced must comply with basic cartographic rules and must therefore have an appropriate cartographic projection, a balanced level of generalization, MMU and attribute details, a suitable set of visual variables and, in the case of quantitative data, a proper method for the classification of the thematic variable.

Even the maps that comply with these rules are often not fully comprehensible for their final users. This may be because the scale used in the final printed maps, the format in which most decision-makers receive the information, is too small or simply because not all the actors involved "speak" the cartographic language.

In order to overcome these issues, new cartographic methods including geovisualization techniques like realistic 3D mapping, are being explored. Other technological advances like sound mapping, fully interactive mapping or animated mapping are still underused in LUC studies. The integration of realistic 3D models with animation and sound will enable the inclusion of moving living creatures (like animals or people), human-made moving objects (like vehicles or windmills), vegetation, topography, buildings, and variations in the atmosphere or the light. Progress of this kind in LUC representation will make LUC maps more realistic and will enhance their communication capabilities, which in turn will help ensure better-informed decision-making processes.

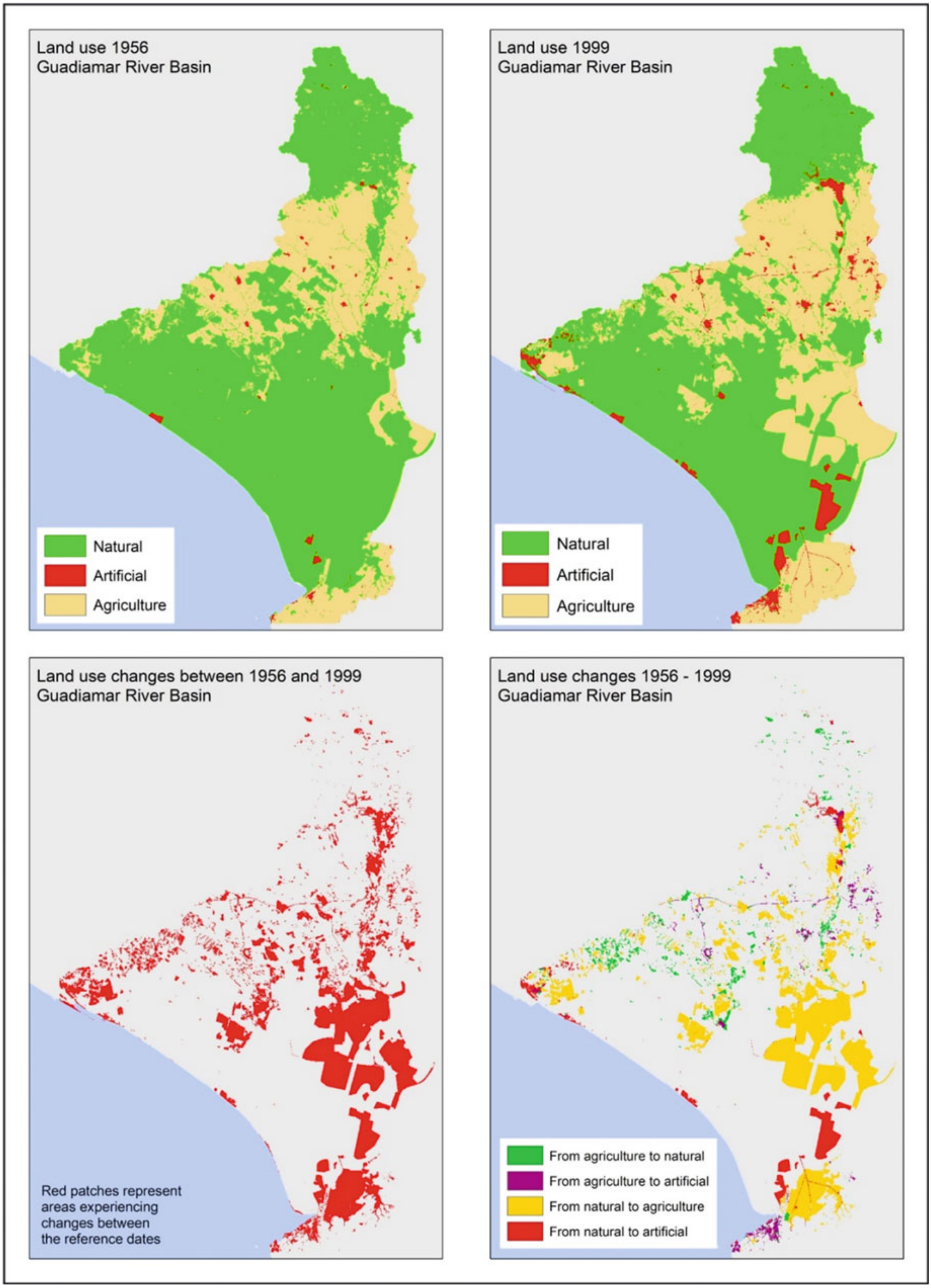

Fig. 10 Cartographic representation of LUC changes

Data Sources The author produced all figures included in this chapter for the purpose of this book. Data sources used are:

- Spanish National Mapping Agency: Instituto Geográfico Nacional (IGN) at www.ign.es;
- Spanish Agency for National Parks: Organismo Autónomo de Parques Nacionales (OAPN) at https://www.miteco.gob.es/es/parques-nacionales-oapn/;
- Spanish National Bureau of Statistics: Instituto Nacional de Estadística (INE) at https://www.ine.es/; and
- European Environment Agency (EEA) at https://www.eea.europa.eu/.

References

Appleton K, Lovett A, Sünnenberg G, Dockerty T (2002) Rural landscape visualisation from GIS databases: a comparison of approaches, options and problems. Comput Environ Urban Syst 26(2–3):141–162

Bertin J (1967) Sémiologie graphique. Les diagrammes, les réseaux et les cartes, Mouton, Gauthier-Villars, Paris, p 431

Brewer C (2021) ColorBrewer Tool. http://www.ColorBrewer.org. Accessed 8 July 2021

Brooks CEP, Carruthers N (1953) Handbook of statistical methods in meteorology. London, p 412

Camacho Olmedo MT, Paegelow M, Mas J-F, Escobar F (eds) (2018) Geomatic approaches for modeling land change scenarios. Springer International Publishing, p 525

Cauvin C, Escobar F, Serradj A (2010a) Thematic cartography and transformations. Wiley, London, p 463

Cauvin C, Escobar F, Serradj A (2010b) Cartography and the impact of the quantitative revolution. Wiley, London, p 408

Cauvin C, Escobar F, Serradj A (2010c) New approaches in thematic cartography. Wiley, London, p 291

Cebrecos A, Domínguez-Berjón MF, Duque I, Franco M, Escobar F (2018) Geographic and statistic stability of deprivation aggregated measures at different spatial units in health research. Appl Geogr 9:9–18

Di Gregorio A, Jansen L (2000) Land Cover Classification System (LCCS): Classification concepts and user manual, FAO, http://www.fao.org/3/x0596e/X0596e00.htm#P-1_0. Accessed 1st July 2021

Eagleson S, Escobar F, Williamson I (2002) Hierarchical Spatial Reasoning theory and GIS technology applied to the automated delineation of administrative boundaries. Comput Environ Urban Syst 26(2002):185–200

Eagleson S, Escobar F, Williamson I (2003) Automating the administration boundary design process using hierarchical spatial reasoning theory and geographical information systems. Int J Geogr Inf Sci 17(2):99–118

European Environment Agency (2017) Technical specifications for the CORINE Land Cover (CLC) pilot projects implemented in the Eastern Partnership countries (2017–2019), Implementation of the Shared Environmental Information System principles and practices in the Eastern Partnership countries (ENI SEIS II East), p 15

García-Álvarez D (2018) Aproximación al estudio de la incertidumbre en la modelización del Cambio de Usos y Coberturas del Suelo (LUCC). PhD Dissertation. Universidad de Granada, p 445

García-Álvarez D, Camacho Olmedo MT, Paegelow M (2019) Sensitivity of a common Land Use Cover Change (LUCC) model to the Minimum Mapping Unit (MMU) and Minimum Mapping Width (MMW) of input maps. Comput Environ Urban Syst 78:101389

Guzman LA, Escobar F, Peña J, Cardona R (2020) A cellular automata-based land-use model as an integrated spatial decision support system for urban planning in developing cities: the case of the Bogotá region. Land Use Policy 92:1–13

Hall ET (1971) La dimension cachée, Seuil, Paris, 1st edn, p 256, 1966, 2nd edn, p 254

Hewitt R, van Delden H, Escobar F (2014) Participatory land use modelling, pathways to an integrated approach. Environ Model Softw 52:149–165

Huntsberger DV (1961) Elements of statistical inference. Allyn & Bacon, Boston, p 528

Koláčny A (1977) Cartographic information. A fundamental concept and term in modern cartography, Cartographica, monograph no 19, pp 39–45

Kull CA (2005) Historical landscape photography as a tool for land use change research. Norsk Geografisk Tidsskrift-Norwegian J Geogr 59:253–268

Monmonier MS (1982) Flat laxity optimisation and rounding in the selection of class intervals. Cartographica 19(1):16–27

Monmonier MS (1993) Mapping it out. Expository cartography for the humanities and social science. University of Chicago Press, Chicago, p 301

Morrison JL (1976) The science of cartography and its essential processes. Int Yearbook Cartogr 16:85–97

Muller JC (1975) Association in choropleth map comparison. Annals Ass Am Geogr (AAAG) 65(3):403–413

NOAA (2011) Digital Coast GeoZone. Tech talk for the Digital Coast. https://geozoneblog.wordpress.com/2011/10/28/resolution-vs-minimum-mapping-unit-size-does-matter/ Accessed 1 July 2021

Olson JM (1975) Experience and the improvement of cartographic communication. Cartogr J 12:94–108

Openshaw S, Taylor PJ (1979) A million or so correlation coefficients: three experiments on the modifiable areal unit problem. In: Wrigley N (ed) Statistical methods in the spatial sciences. Pion, London, pp 127–144

Paar P (2006) Landscape visualizations: applications and requirements of 3Dvisualization software for environmental planning. Comput Environ Urban Syst 30(6):815–839

Pontius RG, Malizia NR (2004) Effect of category aggregation on map comparison. In: Egenhofer MJ, Freksa C, Miller HJ (eds) Third international conference of the geographic information science (GIScience). Springer, Adelphi, pp 251–268

Rajabifard A, Escobar F, Williamson I (2000) Hierarchical spatial reasoning applied to spatial data infrastructures. Cartography 29 (2):41–50

Raposo P, Brewer C, Sparks K (2016) An impressionistic cartographic solution for base map land cover with coarse pixel data. Cartogr Perspect. https://doi.org/10.14714/CP83.1351

Ratajski L (1978) The main characteristics of cartographic communication as a part of theoretical cartography. Int Yearbook Cartogr 18:21–32

Robinson AH (1952) The look of maps: an examination of cartographic design. University of Wisconsin, Madison, US, p 105. Reprinted in The American Cartographer, 13:3, 280, (1986)

Robinson AH (1953) Elements of cartography, 1st edn. John Wiley & Sons, New York, p 245

Robinson AH, Sale R, Morrison J, Muehrcke PC (1984) Elements of cartography, 5th edn. John Wiley & Sons, New York, p 541

Robinson AH (1969) Elements of cartography, 2nd edn. John Wiley & Sons, New York, p 333

Robinson GM (1998) Methods & techniques in human geography. John Wiley & Sons, England, p 390
Slocum TA, Mcmaster RB, Kessler FC, Howard HH (2005) Thematic cartography and geography visualization. Pearson Prentice Hall, p 518
van Lammeren R, Houtkamp J, Colijn S, Hilferink M, Bouwman A (2010) Affective appraisal of 3D land use visualization. Comput Environ Urban Syst 34:465–475
White T (2017) Symbolization and the visual variables. the geographic information science & technology body of knowledge, 2nd Quarter. In: Wilson JP (ed) https://doi.org/10.22224/gistbok/2017.2.3
White R, Engelen G (1993) Cellular dynamics and GIS: Modelling spatial complexity. Geograph Syst 1:237–253
Wu J, Harbin L (2006) Concepts of Scale and Scaling. In: Wu J, Jones KB, Li H, Loucks OL (eds) Scaling and uncertainty analysis in ecology: methods and applications. Springer, Dordrecht, The Netherlands, pp 3–15