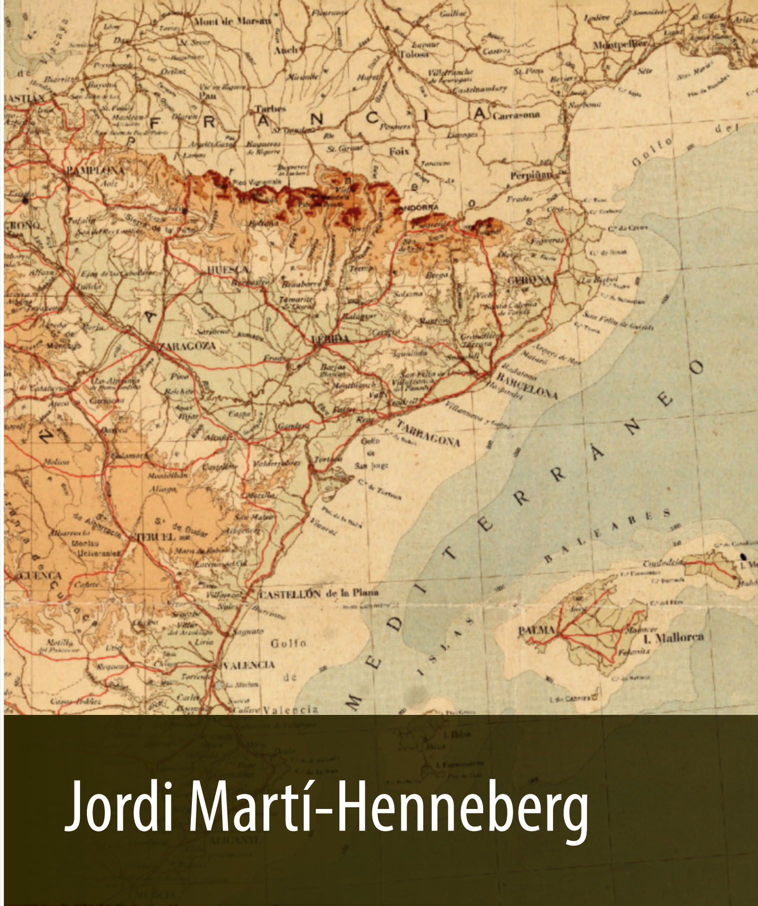

Jordi Martí-Henneberg

Creative Ways to apply Historical GIS

Promoting Research and Teaching about Europe

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Per a la Mercè i els nostres Jaume, Blanca, Laura i Carla.

Introduction

This book is part of an endeavour to promote research as the best way to encourage innovative teaching and learning. With this in mind, there are two particularly important points to underline in this introduction: the scientific and the educational contributions of this book, which were conceived and developed to be complementary. I shall dedicate only a brief comment to the scientific dimension of this work, as this mainly relates to the printed part of the book, which is the most easily accessible. I would like to give rather more attention to the didactic aspects of this publication, as these contents can only be found online: in the Electronic Supplementary Materials (ESM). A peculiarity of this book is that it is divided into two parts, with the second only being available to readers via the Springer website.

My initial idea was to group together several themes of research relating to a Historical GIS (H-GIS) applied to my study of Europe over a period of more than 20 years. These themes deal with three main subjects: regional borders, population, and transport infrastructure, which I have approached in a combined and evolutionary way. This seemed like a good opportunity to present a series of reflections on each theme, both in the form of a general essay, and related to my own contributions, combined with those of many other authors. However, when I started planning this book, I came to the conclusion that – despite the inestimable collaboration of a team, who I cite in the acknowledgements – my own work was not sufficient to cover the very wide spectrum of H-GIS work. With this in mind, I sought collaboration from colleagues who have made very relevant contributions within the fields of: physical geography (Chap. 7), postal services (Chap. 8), the methodology for calculating rail accessibility (Chap. 11), and promoting heritage (Chap. 13). These are four essential chapters, as they highlight themes in which H-GIS research has produced some of its best results. On the other hand, and as it is possible to see from the index, I have written the first four chapters as an individual author. This was not determined by any perceived order of relevance, but because these are the most general chapters. This has also given me an opportunity to offer the public some of the databases that I have compiled over recent years. Finally, I have taken advantage of the co-authorship of other collaborators to develop some of the more specific themes. These include: port connections (Chap. 5), regional disparities (Chap. 6), railway stations (Chaps. 9 and 10), and the process of urban expansion (Chap. 12). Judging from the final results, I can affirm that this is a coherent book and the product of a combined effort to explain the development of each theme and of the ESM. More specifically, each chapter contains an explanation of the methodology used with the hope that this will serve as a source of inspiration and as a model that other researchers will be able to use to further develop each theme.

It is also necessary to underline that, in this work, research is understood in its widest sense: it is not seen as being only restricted to universities and other specialist centres, but as also taking place in schools and associations, and being undertaken by private individuals. The objective of these chapters is to promote this view of research and, more specifically, that conducted through the use of H-GIS. It is, however, necessary to remember that GIS is only a tool. What is important is the task of devising innovative ways of working, and of looking for and using appropriate information. It is also necessary to employ a critical outlook, from the initial planning phase through to the discussion of the final results.

This takes place within the understanding that digital technologies are increasingly central to teaching at all levels. Furthermore, and more specifically, this must serve as a way of rekindling student interest in the social sciences, and in historical geography, in particular. Below, I will examine the didactic considerations which have gradually taken on an increasingly important position in my work and role amongst my interests.

I think that the contribution that this book can make is opportune within the context of the deep-seated changes that are currently underway in the world of education and taking place at all levels. This is particularly relevant to the transition from memory-based learning to another type of education, based on the development of competences. Along these lines, in this publication, we offer tools for developing a form of teaching and learning which is based on providing stimuli and which implies carrying out research in the classroom. This mainly applies to the fields of history and geography, but can also be found in economics and sociology, amongst other social sciences. Moving forward, perhaps the most eloquent innovation in this book is the inclusion of a – previously cited – digital ESM, which contains detailed instructions for developing the tutorials associated with each chapter. The ESM have been conceived to be used in two main ways. One of these involves completing practical exercises in the classroom. To do this, teachers and lecturers will have a wide range of themes to choose from. The second implies users searching for information to meet their own needs. In this way, they can create their own databases and analyse them either following the proposals laid out in this book or using others.

In this line, there are already platforms available for exchanging experiences in secondary education. The main one is eTwinning,[1] which has more than 233,000 associated schools throughout Europe, through which over 139,000 projects have already been carried out. These have been based on collaborations between different schools and have allowed educational centres to obtain solid support for the research work that they carry out.

Teaching and learning innovations are also being spread via projects, in which textbooks are not used to cover the whole of the subject. Instead, the learning process is based on work carried out in small groups which develop complementary aspects of a given theme. Rewards have been created and dissemination channels have been established to promote this type of work, which is often tutored by school teachers with the support of university staff. With time, these types of collaborations between the education sector and researchers have gradually been consolidated. To ensure the didactic utility of this book, the tutorials are also aimed at undergraduate, Master's, and PhD students. This is achieved through exercise aimed at different levels of learning and based on the previous knowledge that they require (Table 1).

All of these pieces of research tend to have the objective of studying areas near the places where the students live, such as their regions or countries. This provides them with reasons for visiting archives or carrying out field work. For this reason, I think that it is necessary that they have access to appropriate methodologies and to examples that can guide and help them to apply the approaches to their own settings and topics of interest. In the chapters and tutorials in this book, the cases developed are naturally limited. However, they are presented in a way that can be applied in any other part of Europe, or even the world.

As previously mentioned, not all research is carried out in specialised centres.[2] With this in mind, and to encourage greater interest in research, this book offers two types of content in each of its 13 chapters. On the one hand, there are texts that provide state-of-the-art information about each theme. In every case, the most relevant aspects of the theme are highlighted in order to provide all the necessary context. A selection of literature has also been included,

[1] https://www.etwinning.net/en/pub/index.htm, co-funded by Erasmus+, the EU programme for Education, Training, Youth and Sport.

[2] The contribution of individuals and associations has always been very relevant. It is important to highlight the contributions from private natural history collections and amateur archaeology and hiking associations, which have made very relevant contributions to the study of geography, natural history, and history since the mid-nineteenth century.

Table 1 Required level of previous knowledge of GIS to be able to do the tutorials in the Electronic Supplementary Materials section of this book

	No previous knowledge	Basic knowledge	Intermediate knowledge	Advanced knowledge
Chapter 1. Boundary Changes in Europe, 1850–2020. States, Regions and Data Analysis	Exercise 1: Calculating population density	Exercise 2. Calculate the population density of a specific region	Exercise 3. Calculating population density: NUTS regions	
Chapter 2. Urbanisation		Exercise 1. Calculating population growth Exercise 2. Calculating distances[a]	Exercise 3. Calculating the rural population	
Chapter 3. Roads and Waterways: The First Inland Transport Systems, and the Subsequent Major Impact of Road Transport	Exercise 1. Making a map of roads and navigable waterways Exercise 2. Map of motorways and dual carriageways in Europe Exercise 3. Traffic intensity	Exercise 4. Roads and municipalities		
Chapter 4. The expansion of Railways in Europe	Exercise 2. Mapping the evolution of the European rail network Extra: download data from other sources	Exercise 1. Railways regional density		
Chapter 5. Ports and Freight Transport in Europe: A Historical Approach	Extra: Download data from other sources	Exercise 1. Distance between the ports and the railway network[a] Exercise 2. Georeferencing of ports	Exercise 3. Ports and sea routes of England and Wales	
Chapter 6. Analysis of Inequalities Between Territories	Exercise 1. NUTS 2 GDP for Europe	Exercise 2. Calculate the growth in GDP Exercise 3. Current GDP Exercise 4. GDP at the judicial region level		Exercise 5. Territorial imbalances at the local scale
Chapter 7. Using Archival Aerial Imagery to Study Landscape Properties and Dynamics			Exercise 1. Land use changes Exercise 2. Topographic changes	
Chapter 8. The Internet of the Nineteenth Century: Railways and the Postal Service in France and Great Britain, 1830–1914				Lab Exercise on the Expansion of Mail Service and Railways in Britain, 1840–1914[a]

(continued)

Table 1 (continued)

	No previous knowledge	Basic knowledge	Intermediate knowledge	Advanced knowledge
Chapter 9. Vector growth			Exercise 1: The city of Girona Exercise 2. The city of Groningen	
Chapter 10. The use of stations in quantitative studies			Exercise 1: Reconstruction of the station network and its link to the territory Exercise 2. Connecting the ports layer to the stations layer Exercise 3. Linking the tracks layer with that of the municipalities	Exercise 4. Generating the least cost path (LCP) from a municipal centre to a station
Chapter 11. Mapping Half a Century of Accessibility via the French Railway Network, 1860–1910			Exercise 1. Morphological analysis in 4 steps	Exercise 2. Functional analysis
Chapter 12. Urban Morphology			Exercise 2. The creation of urban morphological zones: The Hague[a]	Exercise 1. The creation of urban morphological zones: Lleida[a]
Chapter 13. The Network of UNESCO Sites: Changes and Patterns Visualized with Cartograms			Exercise 1. Analysing Changes and Patterns with Cartograms	

[a]For these exercises, it is necessary to use ArcGIS software

without any pretence to this being exhaustive. Relevant case studies have also been selected in order to guide future work. The content and structure of the chapters is not strictly homogeneous, but varies according to the characteristics of each theme. This applies to both the contents available on paper and that digitally published.

Each chapter also contains a set of practical exercises, associated with data that readers will have ready access to. In some cases, these data are stored in open repositories, while in others, they are contained in archives that we have specifically prepared. Those contained in the archives constitute an innovating aspect of this book, as they are materials that are the product of a long process of empirical work and which are now being offered to the public for the first time. These exercises form the ESM and provide a practical manifestation of some of the ideas examined in the printed text. In fact, this ESM forms part of a manual and it contains many graphics that outline the steps that users must follow. Given their extension and detail, these contents only form part of the digital publication, but they can also be easily accessed by users of the paper edition of the book.

In order to facilitate the use of the data, and the future development of the exercises, great efforts have been made to ensure that must data can be accessed using a free version of the GIS (in this case, QGIS). In only a few very specific cases, involving advanced exercises, is it necessary to use ArcGIS, which is a tool that is almost only available at universities and rarely at centres of secondary education. The corresponding details can be consulted in Table 2.

In the pedagogic orientation that has been provided up to here, I have sought to include a tendency that has been gaining more and more ground and which may well become firmly consolidated in the future. As previously outlined, this is the fact that one of the main objectives of learning is now seen as the task of promoting an improvement in student competences, rather than simply increasing their knowledge. The reason for this is that they run the risk of quickly forgetting what they have learnt if this is not applied in a creative way. There is already an extensive general and applied literature on this subject, relating to each area of knowledge. In the field of HGIS, it is currently quite limited, but our task here is precisely that of promoting the use of GIS in the area of teaching history and geography, amongst other disciplines. In the area of H-GIS applied to learning, there are some solid antecedents, such as the works of Gregory and Ell (2007) and Knowles and Hillier (2008). These studies also underline how history can be enriched through the spatial perspective provided by GIS. This is a matter that I made reference to in the introduction to an earlier special issue (Martí-Henneberg 2011). The reconstruction of historical databases is also very useful, as is placing them at the disposal of the public for their use with GIS and other derivatives. There are studies that have normally been performed at the national level, with the antecedents of Britain (Gregory et al. 2002) and the USA (Fitch and Ruggles 2003; Ruggles et al. 2017).

It would require too much space to cite all the antecedents of the application of H-GIS in historical geography and the current projects for the digitalisation of data and their diffusion. Amongst recent projects carried out in Europe, at the national level, it is, however, particularly relevant to highlight the work of Litvine et al. (2020) on France. In the case of my own work, a project financed by the Erasmus+-Jean Monnet Action allowed me to create the Centre of Excellence on European Integration.[3] Looking to the future, our main objective is to digitalise and combine the main transport infrastructure in a single H-GIS and to make this available to the public in 2025. For a review of all these advances, I would recommend making Google Scholar searches using the relevant keywords.[4]

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[3]Title of the 2022–2024 project was: How transport infrastructure has shaped European Integration: A long-term approach (19th–21st centuries).

[4]For example: historical geography, maps, Historical GIS (HGIS), and also other specific key words.

Table 2 Software and external data required for the exercises

Chapter	Title	Software	External open data to be used	Data in Springer website
Chapter 1	Boundary changes in Europe, 1850 – 2020. States, Regions and Data Analysis	QGIS 3.22 (this version can be used in most chapters)	**GISCO NUTS regions (Shapefile format)** https://ec.europa.eu/eurostat/web/gisco **2011 census (CSV format) © European Union 1995-2023, source: Eurostat, © EuroGeographics for the administrative boundaries. Accessed June 2023 (applies for all GISCO data).** https://ec.europa.eu/CensusHub2	Regional population in Europe (GeoPackage format) Census data (CSV format).
Chapter 2	Urbanisation	QGIS 3.22 ArcGIS 10.5	**Cartographic base for Europe (Shapefile format)** https://ec.europa.eu/eurostat/web/gisco	European urban population (GeoPackage and Shapefile format) The railway network (GeoPackage and Shapefile format) Regional population in Europe (GeoPackage format).
Chapter 3	Roads and Waterways: The First Inland Transport Systems and the Subsequent Major Impact of Road Transport	QGIS 3.22	**Cartographic base for Europe (Shapefile format)** https://ec.europa.eu/eurostat/web/gisco **European motorways (Shapefile format)** https://github.com/StudioFolder/european-motorways/ **Municipal boundaries (Shapefile format)** https://centrodedescargas.cnig.es/CentroDescargas/locale?request_locale=en	Roads in Europe, 1835 (GeoPackage format) Traffic intensity layer (GeoPackage format). Roads 1861 and 1963, Spain, Shapefile format. Waterways in Europe (GeoPackage format).
Chapter 4	The Expansion of Railways in Europe	QGIS 3.22	**Cartographic base for Europe (Shapefile format)** https://ec.europa.eu/eurostat/web/gisco	Railway lines in Europe (GeoPackage format) Regional population in Europe (GeoPackage format).
Chapter 5	Ports and Freight Transport in Europe: A Historical Approach	QGIS 3.22 ArcGIS 10.5	**Cartographic base for Europe (Shapefile format)** https://ec.europa.eu/eurostat/web/gisco **Ports in UK and Wales** https://reshare.ukdataservice.ac.uk/853711/	Railway lines in Europe (Shapefile format) Ports in Europe (Shapefile format) external data Cabotage data and port coordinates (.CSV format).

Chapter	Title	Software	External open data to be used	Data in Springer website
Chapter 6	Analysis of Inequalities Between Territories	QGIS 3.16	**NUTS2 and GDP** https://www.wiwi.hu-berlin.de/de/professuren/vwl/wg/roses-wolf-database-on-regional-gdp **NUTS 3, 2021 in Europe** https://ec.europa.eu/eurostat/web/gisco **Gross domestic product (GDP) at current market prices by NUTS 3 regions** https://ec.europa.eu/eurostat/web/products-datasets/-/nama_10r_3gdp https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10r_3gdp&lang=en	Judicial parties (GeoPackage format), by Prof. Fran Beltran. GDP by judicial parties (.CSV format). SVH streets (GeoPackage format). SVH jobs by streets (.CSV format).
Chapter 7	Using Archival Aerial Imagery to Study Landscape Properties and Dynamics	QGIS 3.16 GDC 7		1957 and 2015 orthophotomosaics. 1957 and 2015 digital elevation models.
Chapter 8	The Internet of the Nineteenth Century: Railways and the Postal Service in France and Great Britain: 1830 – 1914.		**Geoda software** https://geodacenter.github.io/index.html	Post offices 1861–1880 (Shapefile format). Brit Mail Rail_Teach (GeoDataBase format).
Chapter 9	Vector growth	QGIS 3.22	**Data on Dutch urbanisation** https://services.rce.geovoorziening.nl/verstedelijking/wfs?request=GetFeature&service=WFS&version=1.1.0&outputFormat=SHAPE-ZIP&typeName=Groeikaart_verstedelijking_NL	Groningen growth (GeoPackage format) Cadastre of the city of Girona, Spain. Girona and Groningen stations, GeoPackage format.
Chapter 10	The use of stations in quantitative studies	QGIS 3.22.7	**Spanish topographical map** https://www.ign.es/wms/primera-edicion-mtn **European coastline** https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-1/gis-data/europe-coastline-shapefile	Railway stations in Spain (Shapefile format). Railway lines in Spain, 1866 (Shapefile format). Ports in Spain (Shapefile format). Spanish provinces, Shapefile format.
Chapter 11	Mapping Half a Century of Accessibility via the French Railway Network, 1830–1910	QGIS 3.4.13		Railway in France / French boundaries / centroid of Paris (Shapefile and GeoPackage format).

(continued)

Chapter	Title	Software	External open data to be used	Data in Springer website
Chapter 12	Urban Morphology in Historical GIS	ArcGIS 10.5	**Atlas van de Verstedelijking in Nederland - groeikaarten.** https://www.nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search#/metadata/ff63434f-7b4a-4346-a4e2-2037adfbcf0c **Urban Morpholohical zones in Europe:** https://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2000-2 **Old map of the city of Lleida, Spain** https://cartotecadigital.icgc.cat/digital/collection/mtn50/id/1143/rec/4 **Old map of the city of Mérida, Spain** http://www.ign.es/web/biblioteca_cartoteca/abnetcl.cgi?TITN=35729 **Spanish aerial photography** https://www.ign.es/wms-inspire/pnoa-ma?request=GetCapabilities&service=WMS	Cadastre of the city of Lleida, Spain.
Chapter 13	The Network of UNESCO Sites: Changes and Patterns Visualised with Cartograms	QGIS 3.16	**Vector dataset of UNESCO world heritage sites in danger and UN subregions** https://github.com/GeowazM/The-Network-of-UNESCO-Sites_Changes-Patterns-visualized-with-Cartograms/blob/main/data/Download-Data_UNESCO_World-Heritage_Sites-in-Danger_HIS-GIS.zip	

As a practical consideration, I would like to add that the majority of the chapters in this publication contain a final section about the contents of their respective ESM. These sections have also been repeated the first paragraphs in the ESM in order to provide a suitable link between the printed part of the work and that which is only available online. I hope that the reader can comfortably find their way around a publication like this, which is provided in two different formats.

Cambridge and Cambrils, July 2022.

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Contents

1 Boundary Changes in Europe, 1850–2020. States, Regions and Data Analysis

Jordi Martí-Henneberg

Abstract

The objective of this chapter is that of developing a historical vision of the establishment of national and regional administrative divisions in modern European states from 1870 through to the present day. It will describe the territorial-administrative structures in each country.

This work will be a novelty in the sense that it will adopt a fairly long-term perspective that will allow us to interpret changes in regional organisation in terms of historical legacies.

The historical map series for Europe presented here aims to provide valuable material for both research and teaching activities. It will be an optimal tool for representing different types of territorial phenomena relating to demographic, economic and/or social questions. Its strong point is that it is based on providing cartographic representations of all of the different administrative units that were operative at each specific moment in history.

Another important aspect concerns what this mapping tool can be used for. Its main function is for the geographic analysis of data obtained from primary sources or indicators based upon them. The sources are mainly the censuses that different countries began to compile at different dates in the nineteenth century. These data have made it possible to construct datasets with the objective of interpreting the evolution of territorial contrasts in Europe covering all of those aspects for which information is available for one or more countries. In the territorial analysis, it is also necessary to take into account the evolution of the factors that have determined these trends. As we will see also in other chapters, we have already carried out this type of research when studying population changes or the impact of the railway network on regional disparities in Europe. It will therefore be possible to continue carrying out studies based on real regional units relating to each historical period.

Keywords

Boundary · Regions · Europe · H-GIS · Nineteenth to twenty-first century

When we travel by plane, sitting next to the window, and observing the territory, one of the most striking things that we observe is the continuity in the different woodlands, plains and mountains that we see. The countries and regions that we pass over do not have different colours, as they do on school maps and atlases. The natural and human landscape is not divided by any political boundaries, and there seems to be a continuum of cities, scattered houses, meadows and rivers. On landing, however, we realise that there are limits of all kinds, including borders, which are also reflected in different police uniforms, in different coloured traffic signals and in many other ways. Borders are an essential reference in the organisation of our life within society, and we must be particularly aware of those that have been erected as walls that separate and segregate people.

The subject of borders is one of the themes that have received most attention in political geography and also in many other disciplines.[1] They have also been incorporated as one of the layers in GIS and in a wide variety of scientific, educational and journalistic databases.[2] In this case, the utility of borders lies in the fact that they structure and detail the information that

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[1] It is possible to cite several works that have followed this line (O'Dowd 2002), some of which are now classical studies, such as the reference atlas (Christopher 1999).

[2] Newspapers such as *The Guardian*, *El Pais* or *Le Monde* have, for some time, included digital maps showing regions and municipalities to support their articles.

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we have about a particular space. As a result, they allow us to detect contrasts between different territories, based on a wide variety of indicators. These may include the distribution of per capita GDP between the provinces of a particular state or the rate of diffusion of an illness between the municipalities in a given region.[3] Furthermore, if the same type of data is available for a long period, it is possible to carry out a fundamental exercise of analysis: a comparison over time. It is precisely with this end in mind that it is preferable to work with stable territorial units and to use them as points of reference; these may be the districts within a city or the municipalities or provinces within a state. In our studies, it is essential to use both of these essential dimensions: space and time. With this in mind, it is necessary to start with a knowledge of the territorial structure that we plan to use.

Within this context, we shall examine two issues in this chapter. Firstly, based on the case of Europe, we shall compare areas and periods of stability, which contrast with situations characterised by major changes in the borders of different states and regions. Secondly, in Sect. 1.2, we shall discuss the problem of how such changes limit the capacity for territorial analysis. This second issue will be fully developed in the rest of the chapters in this book, as it is relevant to various different themes. As we shall see, the challenge facing long-term spatial studies is that they normally relate to borders that may change over time. The main problem deriving from this is that the territories to which the available official data correspond cannot then be used for comparative reference. Historical-GIS (H-GIS) techniques allow us to propose viable options in some cases, but there are no definitive solutions. In order to harmonise data series that refer to changing territorial units, we have applied smoothing techniques; this should be taken into consideration (Gregory 2002; Gregory et al. 2010). In the final section, we shall provide data and guidelines that will help teaching and research work when the content includes data referring to borders.

Section 1.1 shall explain and interpret the meaning of "border changes" as used in this book. A distinction will be made between two scales, because of their political implications. The first consists of a single category, the state, and relates to sovereign entities. The factors that explain changes in a state's territorial morphology have little to do with its regions or local units; these are grouped together at the second level. Regions are basically domestic administrative divisions, which are subject to the competence of the state.

[3] Studies of epidemiology and medical geography have experienced tremendous growth throughout the world as a way of analysing the diffusion of COVID-19.

1.1 Border Changes in Europe

In this section, we shall study both of the levels referred to above: states and their internal subdivisions, or regions. The latter receive different names according to the state in question (Table 1.1). In the first section, I shall refer to the context and causes of changes to national borders. I will refer to these as "state borders", given the relative neutrality of this term. Although each state is sovereign with regard to its internal administrative geography, there are as we shall see also several common patterns. Each state has competences to organise the local units within its sovereign territory. However, despite its relevance (Rokkan 1999; Flora 1983), this level will not be examined in the present chapter.

1.1.1 Changes in State Borders

One essential function of a state is that of defending its territory and maintaining its unity, which is ultimately the responsibility of its army. Establishing borders does not promote stability but instead is often a source of tension and conflict. Since they first emerged, states have manoeuvred to extend their territories and to subdue those of other societies. This is what has often been referred to as extending and ensuring their "living space" (Mackinder 2004; Sloan 1999). Territory is a limited commodity, and since Mediaeval times, it has often been fiercely disputed by different states, particularly in parts of the world like Europe. For this reason, extending the size of one state effectively implies losses for neighbouring states. Tension is therefore inevitable, and this has caused wars in many areas with pre-established borders. In the Old Continent, this has been a key factor in a succession of wars and particularly during Modern History. In other continents, the availability of large territories and unexploited resources has tended to relax, although not completely rule out, similar border-related tensions.

There is one piece of work that provides a global vision of border changes in the different states of the world (Christopher 1999). Its global perspective, which compares post-colonial borders on other continents, enables us to see how Europe is clearly the continent that has experienced the greatest state border changes. These have, almost without exception, been the result of wars or major tensions between the mosaic of societies and cultures that form Europe. In some cases, these tensions were bottled up by a powerful force for many years but later emerged when new circumstances allowed. Illustrative examples of this can be seen in the disintegration of the USSR, following the fall of the Berlin Wall (1989) and the aftermath of the civil war in the ex-Yugoslavia (1991–2001). During the period studied in this chapter (1850–2020), the border changes experienced in Europe, which have

Table 1.1 Denominations of regional units by country

Country	Unit name
Albania	Rreth
Austria	Bundesland
Austria-Hungary	Crowland/Megye
Belgium	Province
Bulgaria	Okrag
Czechoslovakia	Kraj/Mesto/Hlavni Mesto
Denmark	County
Finland	Region
France	Department
Germany	Bundesland/Regierungsbezirk/Verwaltungsbezirk
Germany (GDR)	Bezirk (−1952: Land/Bezirk)
Greece	Nomoi
Hungary	Megye
Ireland	County/county Borough
Italy	Regioni
Luxembourg	Grand Duchy
Malta	Republic
Norway	County
Poland	Województwo
Portugal	District
Romania	Judetul
Spain	Province
Sweden	County
Switzerland	Kanton/Halbkanton
The Netherlands	Provincie
UK (England)	Administrative County (incl. County Boroughs)
UK (Northern Ireland)	(Civil) county and county Borough
UK (Scotland)	Single/two-tier system
UK (Wales)	County/two-tier-system/(−1974: Administrative County)
Yugoslavia	Socialisticna Republika/Autonomous Province/Republic excl. Autonomous regions

subsequently been consolidated, have occurred for two main reasons: (1) as a result of the independence gained by territories that have established new states, often following quite traumatic processes[4], and (2) or as a result of peace treaties after periods of conflict (Fig. 1.1).

On the other hand, the perceptions that most societies have of changes to their external borders tend to vary greatly and to depend on the recent history of each state and society. We can take two well-contrasted cases, Poland and Spain, as points of reference. A good number of the Poles born after 1918 were born in states that were different from their current country. This was due to the many, and often radical, changes to the shape of their state (Schulte 2021). At the other extreme, Spain has had the same, unchanged, external borders since the seventeenth century. In Spain, this constancy, which is unique within Europe, is also reflected in the internal administration of its territory: its provinces have remained unchanged since 1833. For this reason, in Spain, borders are firmly established within the collective imagination, if not to say, almost set in stone.

In the rest of Europe, however, border changes have affected every state since 1905, the year in which Norway gained its independence from Sweden. One relevant question here is how these changes have influenced the evolution of the borders within each of these states. It is surprising that – as we shall see in the following section – this administrative level has experienced a considerable degree of stability in much of Western Europe. When changes have taken place at this level, it has been for one of three reasons: due to a new regime (as in Germany or Hungary); because of the creation of a new state (Poland, the Czech Republic or Slovakia); or as a consequence of general administrative modifications undertaken in all the other states (Figs. 1.2, 1.3 and 1.4).

Finally, it is necessary to limit the geographical scope of this book to the dynamics of the states that form part of Europe. To put this in another way, any decision concerning how far east Europe reaches is always going to be controversial. Furthermore, it should be noted that for the scope of this

[4]The access to independence of the Baltic states and the Czech and Slovak Republics was not the direct consequence of war but was related to a traumatic period characterised by repression from the USSR.

Fig. 1.1 State borders in Europe, 1871 and 2020

book, the easternmost limits of Europe have varied. The decision concerning which countries to include and which not, in other words, what we consider to constitute Europe, is not without its problems from a historical perspective. There were no doubts concerning the inclusion of the space formed by the 27 states that currently form the European Union, plus the United Kingdom, Switzerland, Iceland and Norway, as they all clearly belong to Europe. Problems arise when we consider the space corresponding to Central Europe. This is occupied by political entities that have undergone major changes since they belonged to the German and Austro-Hungarian empires. Including the territories that they occupied in 1850 would mean doing the same with the countries that were created following their disintegration: Poland, the Czech Republic, Slovakia, Hungary, Bulgaria and Romania. Going further, and including the rest of the countries that formed part of what was once Yugoslavia and the USSR, and which do not form part of the EU, would imply problems obtaining data that are not already available to us. In short, I had to exclude Turkey from this phase of the research and also the areas that formed part of the USSR, with the exception of the three Baltic Republics.

1.1.2 Changes in Regional Boundaries

With reference to changes in regions, it is necessary to take into account that the factors that explain their existence are very different from those relating to states. A first general observation is that there is a continuous area, characterised by

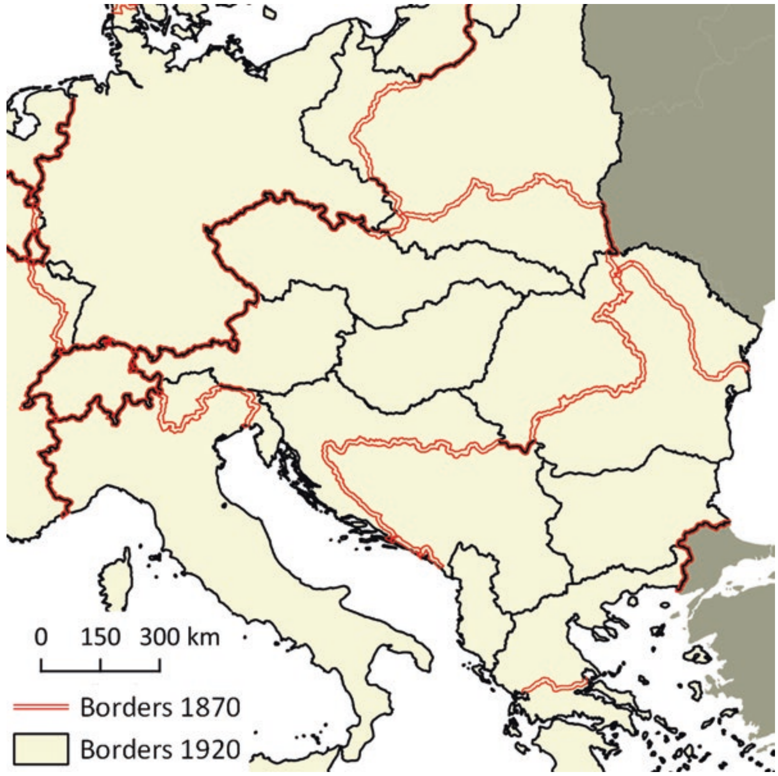

Fig. 1.2 European national borders 1871–1920

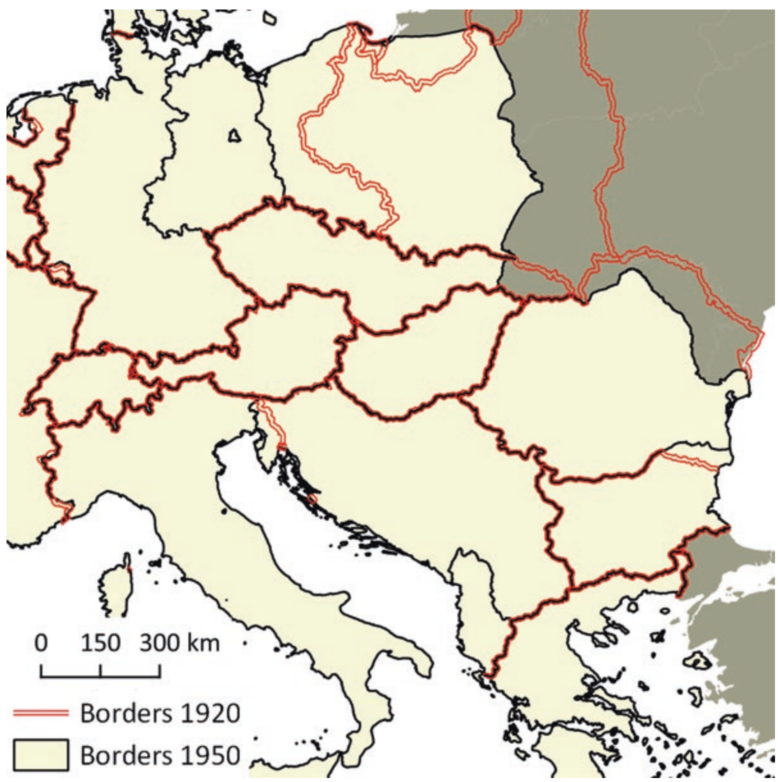

Fig. 1.3 European national borders 1920–1950

great stability, running from the Netherlands to Portugal, while the United Kingdom and the countries of Central Europe have undergone considerable modifications (Figs. 1.5 and 1.6 which presents a new way to identify the areas of major regional changes). Furthermore, within the area of relative stability, the sizes of the regions are relatively similar in each country. It is therefore necessary to explore whether there are any common patterns shared by these two groups of

Fig. 1.4 European national borders 1950–2020

countries; this is a subject to which the two following subsections have been devoted. However, it is necessary to underline that this grouping is always open to discussion; furthermore, the casuistry of territorial administration is highly diverse, as each state has followed its own logic. As we shall see, the diffusion of the Napoleonic model is clear amongst the countries that present the greatest degree of stability. In contrast, the more heterogeneous group is also the most varied, and precisely because of its central characteristic: as far as possible, it has maintained border divisions that date back to the time of the *Ancien Régime* and which do not follow the logic of a centralist state. Territorial organisation ultimately took on one of two, clearly distinct, forms: regular or asymmetric. Based on this logic, Europe territorial organisation can be divided into two models. The denominations that we suggest giving them are "rationalist" and "historicist". The former is characterised by a marked break with the *Ancien Régime*, while the latter remained loyal to the legacy of the past but was also often flexible in terms of adapting to change.

In the next two sections, we shall not only describe the historical maps in Europe. We shall also present the keys for understanding the transformations that took place between 1850 and 2020. One general point of reference is the fact that the administrative organisation of a territory constituted a vital instrument of political action during the liberal reforms undertaken in the nineteenth century. Territorial divisions therefore provided a hierarchy of power which, in combination with newly introduced population censuses, made it possible for governments to introduce several innovative initiatives, ranging from fiscal policy through to military recruitment.

1.1.2.1 The Rationalist Model

There are two essential elements for interpreting territorial administration in Europe: the morphology of the regions and their competencies. The two are virtually inseparable in what I call the "rationalist" model, which was initially conceived and applied by a new form of government that had its origins in the French Revolution (1789). Given its innovative character, it is important to explain the French case in greater detail (Motte 2021; Souchon and Antonie 2003) and to look at the countries that subsequently adopted it. The great importance that the new French government gave to administrative reform is evident from the fact that it was first discussed in 1789 and was approved and applied in 1790. The aim of creating what was to be a new type of state was reflected by the establishment of an administration divided into departments of a similar size and with identical powers, as an expression of the will to apply the principle of equality. As we can see, the morphology of the units and their competencies shared the unifying rationalism that inspired their creation.

The change of regime that came with the appointment of Napoleon Bonaparte as First Consul, in 1799, did not imply modifying the organisation of the territory but rather a reform of its content with the central power of the state being rein-

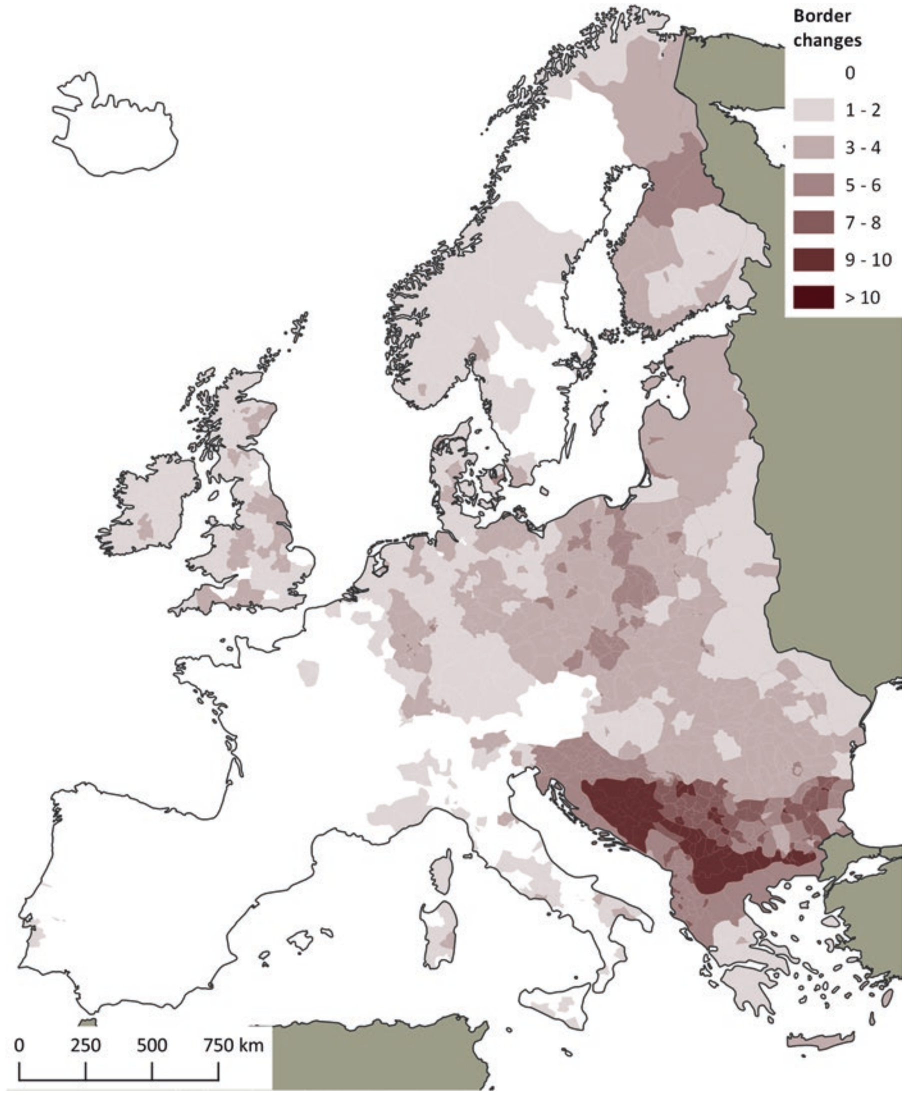

Fig. 1.5 The evolution of regional borders

forced. The centralism, which is so much criticised today, represented greater modernity in the territorial administration of the state at that time.

In the case of Belgium (Goossens and Hendriks 2021), which was annexed by France in 1795, the country was divided into nine departments; these have since been maintained until the present day, with only minimal modifications. The case of the Netherlands (Hendriks and Goossens 2021) is more complex. During the Napoleonic period (1795–1813), they adopted a centralised form of administrative organisation, with hardly any local autonomy. Later, they maintained the principle of uniformity of powers at three different levels as a result of a reform sponsored by the liberal prime minister Johan R. Thorbecke. In 1851, the number of administrative districts was increased to 11, but both the central and municipal administrations were given wide-ranging powers. The intermediate level of administration therefore lost power, but its representatives began to be directly elected. Despite deep-seated reform undertaken at the municipal level since the 1970s, this system has been maintained until today. In the Netherlands, as in other countries of Napoleonic influence, the most fundamental consideration has not only been the stability of the boundary divisions but also that of the hierarchical and functional organisation of each administration. The power of each administrative unit has remained the same, despite differences in their size and relevance.

The diffusion of this rationalist model can be seen by simply observing the countries in which the administrative map is most regular and stable (Fig. 1.5). In fact, in the nineteenth century, Belgium, the Netherlands, Spain and Portugal adopted homogeneous administrative divisions, which have remained virtually unchanged ever since. In spatio-temporal terms, the main characteristic of the rationalist model is the stability of its borders over time. This totally contrasts with what we observe in the "historicist" model.

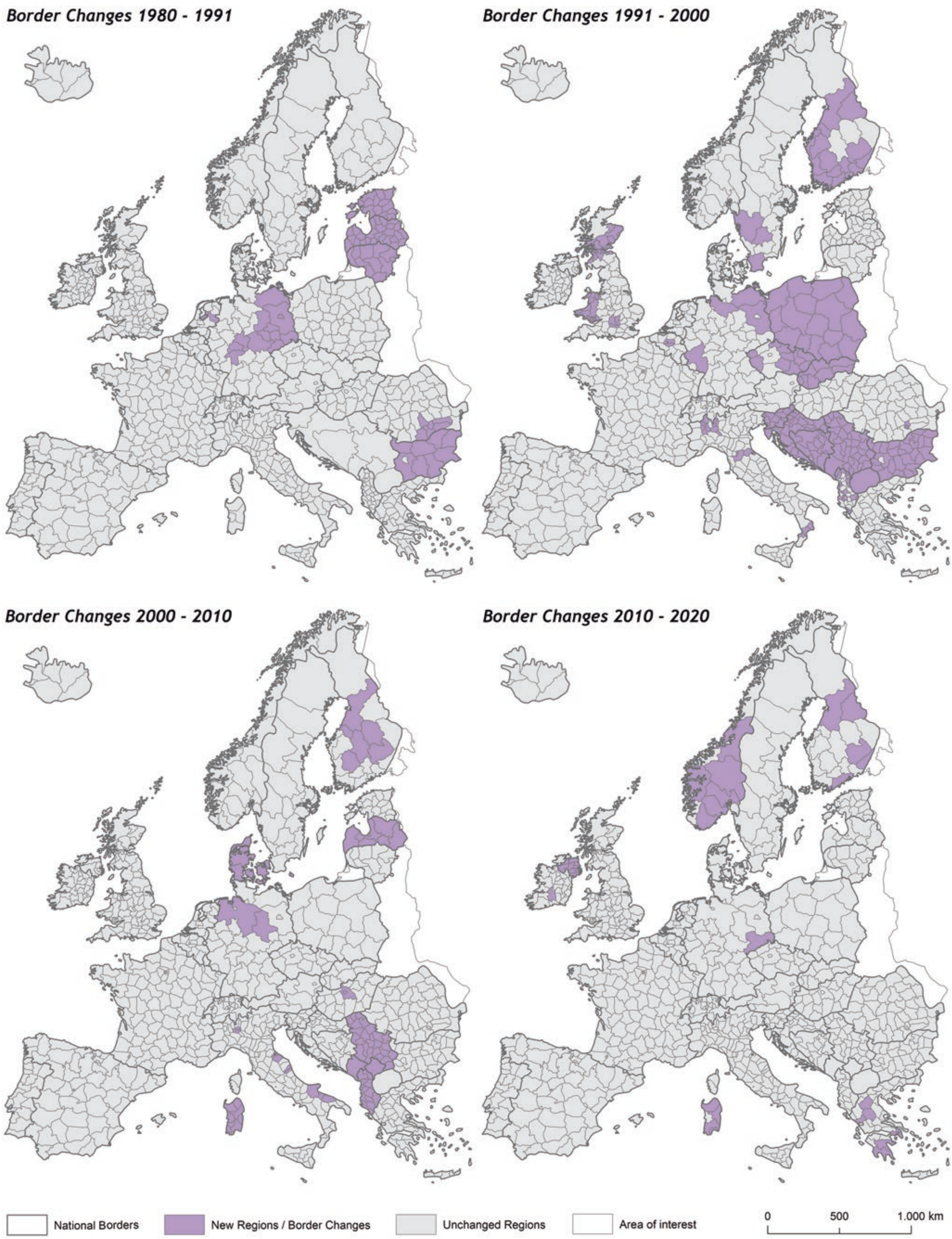

Fig. 1.6 Intensity of regional border changes, by area, 1980-2020

1.1.2.2 The "Historicist" Model

The historicist model encompasses a highly diverse range of territorial morphologies. In contrast to the rationalist model, it has sought to conserve territories that have a distinct historical and cultural identity. This has inevitably implied a greater degree of heterogeneity and the consolidation of regions with solid historical roots. It has, above all, developed in states constructed on the base of previous pacts between different societies with deep-seated historical roots. Consistent with its origins, this model therefore includes a collection of very diverse realities. This point is well illustrated by the cases of Switzerland and Germany, which share the condition of having been initially constructed as federal states. Another very specific case is that of the United Kingdom. We shall also very briefly comment on the case of Italy, as it presents a curious example of ambivalence, occupying a position between the two models.

The case of Italy (Bettoni 2021) is somewhat unusual because the Napoleonic influence is evident in the logic established for its provinces, which have given rise to the current Nuts 3 level administrative units. In contrast, its regions, which correspond to the current Nuts 2 level, have a strong historical anchor and, as a result, are characterised by their heterogeneity. This has been the fruit of both a tumultuous internal history and of the many changes that their external boundaries have suffered. It is not, therefore, surprising to observe a relatively large number of rather peculiar situations in Italy. On the one hand, there are regions, such as Tuscany, which have been relatively stable over time and which are well defined in space. On the other hand, Italy is a country that contains some of the most recently created regions in Europe. One case in point is Valle d'Aosta, which broke away from Piedmont and achieved the status of being an autonomous region with a special regime in 1948.

In summary, the casuistry of territorial administration is very diverse in Europe. Each state has its own historical logic and it is rather difficult to establish classifications. Even so, from the perspective of the stability of state and regional borders, it is possible to divide Europe into two main areas. The rationalist group is mainly formed by contiguous states, while the historicist group tends to be based on long-standing regional boundaries. One clear conclusion that can be drawn is that, historically speaking, regional divisions have performed a practical function with regard to the internal organisation of each state. Both the distribution of competencies and administrative geography were originally viewed as being basically internal questions that had relatively little political relevance. This changed, however, with the institutional consolidation of the EU. There were two reasons for this: devolution processes, which were especially relevant in Spain, the United Kingdom and Italy, and policies of simple decentralisation, like those applied in France. This subject has already been widely treated and is therefore not a central objective of this chapter. The second question does directly affect our subject, as it involves using these antecedents to explain the administrative map of Europe. This has been specifically adapted to incorporate the different levels of the regional map of the EU and of other countries in the area. This line of collaborative work involving different states has consisted of trying (although not necessarily succeeding) to group together the different units in each state in a coherent way. This basically relates to the Nuts 2 and 3 levels, which are the main administrative levels used as references when making decisions about investment in regions based on the redistribution policies of the EU. These policies began with the signing of the Treaty of Rome (1957), which created the European Economic Community (EEC), and were first put into action in the 1960s. Here, we are interested in analysing whether these regions correspond to real units that can be found in each state. In fact, the Nuts 2 level divisions did, initially, in the majority of EU countries, with the notable exceptions of countries the United Kingdom, Finland and France.[5]

1.2 The Creation of the Digital Map

The previous historical vision will help us interpret the morphology and problems associated with the official map of the regions of Europe. The reflections that we have made so far, with respect to the evolution of the regional map of Europe, have allowed us to provide input and to thereby focus on its use at different scales.

The reason for this is that, as previously noted, the hierarchical classification that the EU uses has three different regional levels: NUTS 1, 2 and 3. However, this classification presents two problems: it is not well adapted to the real units found in each country, and furthermore, it does not take into account all the modifications that have taken place over time. The first inconvenience is due to the fact that the European states, and particularly the largest of them, tend to have two levels of regional administration, not three. As a result, one of the Nuts levels does not correspond to observable reality. The missing level is normally level 1, which is only really present in Germany, where it corresponds to the country's federal states. Furthermore, the previously mentioned classification is rather rigid, as it refers to the regions that were established when the EEC was originally set up. Other states were then incorporated at a later date. Even so, these borders had little in common with those that existed prior to WWII. This was an important conditioning factor in terms of the historical analysis that we have carried out in this chapter and in relation to the majority of the themes examined in this book.

[5] Germany has a different hierarchy. There is a NUTS 1 level, which corresponds to its federal states, but its NUTs 2 level is the one which is really most comparable with the other states.

The majority of the cartographic representations that are made relating to Europe use either recent data or data since 1960, which have only been affected by modifications to the borders of the area corresponding to the ex-Yugoslavia. The aim of this book, however, is to use data relating to a much wider historical series. The maps that are presented here allow us to show data at the regional level referring to short, 10-year intervals since 1850.

One critical vision, which derives from what I have said so far, is that the EU has a coherent regional structure. All divisions no doubt have a certain lack of coherence. Without a doubt, this is almost inevitable in countries with long and dense histories of human settlement, in which such administrative divisions have been created. This is still common in countries in which attempts have been made to respect old borders, because new administrative needs often have little or no relation with those of the past. As a result, it is not realistic to expect that territorial units that remain in place like fossils from the past should remain relevant and prove useful for managing the needs of modern-day society.

1.3 Tutorial

The digital map of Europe provided in this chapter has been designed to work on historical geography. To create it, one fundamental consideration was that this type of map should be both correct in terms of history and also appropriate for geographical analysis. Its analytical utility depends on the units chosen being of dimensions that are as similar as possible in order to permit comparisons. It has therefore been necessary to seek a balance between three different parameters: the dimension of the territorial units, the existence and availability of official data at this level and, finally, their permanence over time.

We should now return to the question of what the map of Central and Western Europe discussed in this section should serve for. Firstly, it should be able to show any type of data about historical regions since 1850. This will allow us to study the evolution of territorial contrasts relating to each specific theme, without us having to adapt the information to modern day regions. In this way, it will be possible to ask, and answer, questions such as: How have contrasts between regions evolved over the last 170 years?

Some of these issues will be studied in other chapters in this book. The general tendency that we have observed has been for a relative convergence between regions with respect to the majority of the indicators, such as the provision of infrastructure or of GDP. The most notable exception to this trend relates to *population density* and is associated with the degree of *urbanisation* (Chap. 2). In this case, asymmetry has grown between overpopulated areas and others tending toward extreme depopulation. We insist on the interest in showing these phenomena at a historical scale in order to interpret the most recent processes. A growing number of authors agree on the need for a *path-dependent* perspective to interpret contemporary phenomena (Acemoglu et al. 2005). One example of this is the previously commented analysis of regional disparities, which provide the basis for a subject of such current relevance as regional cohesion within Europe. I do not think that it is possible to continue discussing this question by only looking at what has occurred in the EU in the past 60 years. The fact is that these contrasts have crystallised in Europe as a result of a long historical process, and so it is only from this perspective that we can really interpret the present.

To give a few specific examples, the Nuts level 2 includes regions such as Catalonia (and Languedoc-Roussillon) which contain very diverse realities at the demographic and social levels and which we need to differentiate. This is only possible within a more detailed analysis that is able to distinguish between provinces with characteristics that are too different to be grouped together within the same unit, such as Barcelona and Lleida, in Catalonia, or the departments of Pyrennées and Aude, in Languedoc-Roussillon.

On the other hand, the map that we propose here is similar to those used by other specialists (Todd 1995), for analyses that have appeared in the press, or by certain specific institutions (ESPON). Tables 1.1 and 1.2 in a former article (Martí-Henneberg 2002[6]) were created to justify this option. In Table 1.1 of this article, we can see the evolution of the average surface area of the units chosen in each state. It is also possible to compare these data, which is what interests us here. The dissimilarity in size between the different regions (in km^2) is great in Austria, Italy and Finland. In the case of Austria, this has not been the result of the border changes that took place after the First World War. In Italy, it is due to the fact that we have opted to use the higher, regional, level. In Finland, the large average surface area is due to the peculiarity of the country, which is formed by great areas of territory that are practically unpopulated in the north. The areas in Sweden and Norway are also above average for this same reason. At the other extreme, we find Switzerland, which has very small units, for historical reasons, which I will refer to later. The average sizes of the rest, however, range from 5000 km^2 to 15,000 km^2, with the resulting map being like a board made up of what are generally homogeneous units.

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[6]In this article, Cuadro means Table.

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Urbanisation

2

Jordi Martí-Henneberg

Abstract

Quantifying the formation of agglomerations is of analytical interest and is also an accepted indicator of economic growth. In these lines, measuring the evolution of urbanisation in Europe over the past 170 years is a subject of interdisciplinary interest. The objective is to provide a general overview of the subject, to define the urban area and to quantify its population and morphological changes. This analysis involves the combined use of census data and different sources to study the expansion of the built-up area.

Urban population data has the potential to be used as a socioeconomic indicator to assess at least two aspects: the uneven regional growth of Europe and the relationship between urbanisation and per capita GDP and the extent to which urbanisation could be considered either a precondition for, or a consequence of, economic growth.

The novelty of this approach lies in the fact that (1) in the future, it should provide comparable data about urban population through history; (2) it will offer the possibility to analyse urbanisation within the context of the wider rural population; and (3) it provides an interpretation of urbanisation combining morphology and population changes.

Keywords

Urbanisation · Europe · History · H-GIS · Data

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The city is probably the most sophisticated of all human creations (Fig. 2.1). Its morphology and patterns of growth allow us to interpret the ways in which the society that designed and built it was organised. Due to its complexity and symbology, the city has been the preferred object of study of various different disciplines and has even become the central focus of several consolidated areas of knowledge, such as urban sociology, urban history and urban economics, amongst others. From the time of Plato to the long-awaited smart city, various utopias have placed their social laboratory in the city. In this sense, urban planning provides a reflection of how various ideologies have sought to organise society.

Given the sheer size of this subject, we must carefully define the precise context that this chapter will examine. The study of urbanisation has been undertaken following two main approaches. The first of these is the analysis of the morphology of the contiguous built-up area; the other is the study of the evolution of its total population. As we shall see in Chap. 12, the combination of both perspectives is what will allow us to make a rigorous comparative analysis of long-term urban growth. This is a combined analysis, which is quite complex and difficult to carry out for periods before the mid twentieth century, but it is a line of work on urban history with great potential for the future. In this chapter, we shall set out the bases for this approach, by examining the following aspects, in this order: (1) the persistence of the city throughout history and some significant ideas that have been developed to plan it; (2) the definition of urban space; (3) the factors that explain its expansion; (4) a presentation of a research agenda based on the themes treated here. Some of the aspects of this research agenda are developed in Section (5), which includes a commentary about the data available and tutorials that readers are suggested to work with, which are *the growth of each city in Europe, its relationship with the transport infrastructures and its regional context.*

Thus, in addition to the contents available in each chapter, Sect. 2.4 proposes a line of work in urban history, which, when undertaken, will make it possible to study long-term urban growth with precision. As we shall explain, this

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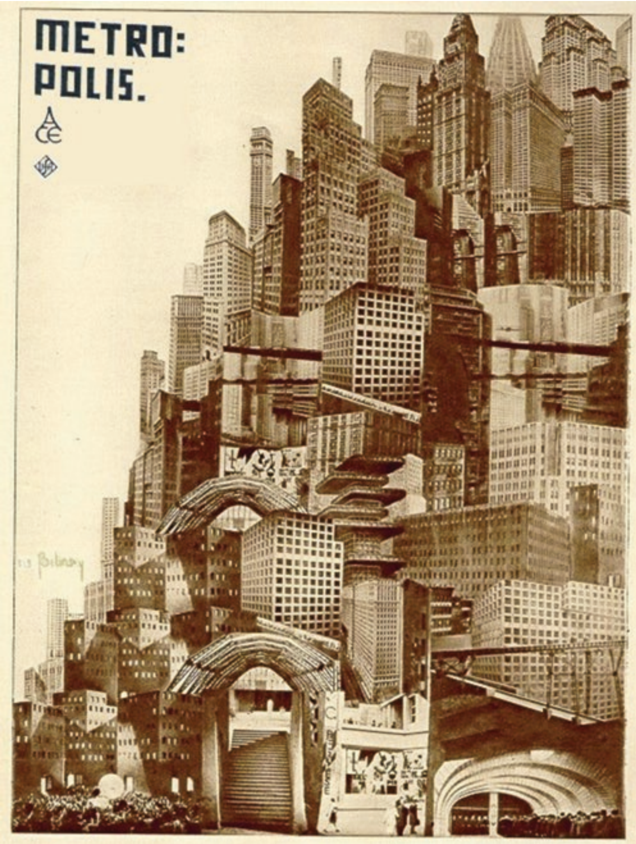

Fig. 2.1 Metropolis. (Source: Konstantinowitsch 1927)

involves quantifying the real population of each agglomeration without the limitations imposed by administrative boundaries.

2.1 The Persistence of the City Throughout History

Since its origins, the urban phenomenon has been linked to the need to establish regulations in all organised societies, but it has also been associated with the pursuit of creating the ideal city (Fig. 2.2).

The dialogue between these two components has been ongoing since the first cities emerged in the ancient world and has continued through to today's smart cities. The city has been the objective of study and reflection from different perspectives and disciplines. Something which is common to all cities is that, without exception, they have had three fundamental elements: they created a sacred space; they provided security; and they housed a commercial market. Starting from this common base, ancient cities intensified one or other of these aspects. In the Mediterranean world, the Phoenician and Carthaginian cultures were ruled by traders. However, both eventually succumbed to cities which were more combative (those of Greece) and to entities with an imperial vision (the Romans). Crete was the first urban civilisation in what is currently considered European territory and was the base for the Greek culture, which became solidly established in its cities. However, in Greek cities, trade was not the most important of the three elements previously cited. In fact, the agora began by being mainly a symbolic reference and a place for meetings. It was only at a later date that it gained importance as a market place (Kotkin 2006). However, as they did not organise themselves into a stable confederation, the Greek cities finally succumbed to external domination. Even so, their idea of the city has remained a point of reference for the Western world. This explains why the city occupies such a prominent position in Plato's "The Republic". To be more precise, in his dialogue "Laws", he conceived the city as a space that should seek to promote a harmonious relationship between the individual and society. Although Plato did not specify the morphology of his reference city, which he called Magnesia, he laid down the main principles for a city mode. This was to be based around the proportions 1:2:3 and to have three concentric areas linked to a radial network of communications. The centre of the city would contain the citadel, the main temples and the agora, which would form a common space in which to forge relationships between the local inhabitants. The parts, or sections, of the previously citied circles would be areas reserved for interaction between neighbours. In this way, Plato planned a model city designed for a maximum of 5040 inhabitants, based on the number of neighbourhoods and families who should form part of it. This system was the result of the Platonic idea that the finite constituted which could be understood and controlled and that Good and Beauty can only be manifest within what is limited. Although this was a utopic ideal, it remains clear, from their very origins, that every city is the result of a certain ideological plan. The individualism which is promoted by today's dispersed city is also the result of adopting a certain ideological option. Thus, it has been throughout the history of urbanism, which is an embodiment of political philosophy. This is also manifested in the thought of one of Plato's disciples, Aristotle, and expressed in his work "Politics". Aristotle saw the human being as a political animal which tended to group together and to live in communities, which is what gave rise to the organisation of the city-state. In reality, the word "politics" derives from the Greek word "polis", which is often translated as "city-state" and includes the area under its control.[1] Also, in the case of Aristotle, the central interest in the "polis" was based on its capacity to appropriately organise the ties between the individual and society.

Later, the Roman Empire reaffirmed the role of the city as an essential part of the territorial structure of its widespread

[1] Sparta, the largest state, had a total area of around 8500 km^2, while that of Athens was about 2600 km^2.

Fig. 2.2 Opera Paris Metro. (Source: Illustreret Norsk Konverastionsleksikon 1913)

possessions. The unity of the empire was based on a system of integrated transportation (Carreras and De Soto 2013a, 2013b, 2021) in which the main nodes were cities which gave structure to the whole system. Within it, the road network was what often conditioned the creation of new cities, and not vice versa. This approach has been reproduced in the current project for the creation of new cities in China, along the corridors of the silk road. The transport infrastructure is again conditioning the establishment of a new network of cities.

The fall of the Roman Empire opened the way to a period in which cities tended to decline, although many of them gradually consolidated their autonomy, particularly when they found themselves in weak states. Surprisingly, given the nomadic origins of this culture, it was Islam which then promoted the founding and development of cities, which were conceived of places that could facilitate the meeting of people in order to pray. In India, Muslims gave great importance to cities, but in Europe, they were only really found on the Iberian Peninsula and in part of Italy.

In contrast, the cities of the north of Italy became consolidated, although they eventually entered a period of decadence as a result of not having managed to unite within a state. In was in this field that the colonial empires of Portugal and Spain took the lead. However, nothing lasts forever, and their main cities (Lisbon, Seville and Madrid) failed to become colonial powers. This was mainly due to questions of ideology and priorities. During the revolt of 1572 in Flanders, the Emperor Charles V opted for a war based on religious unity, with the result that protestant traders moved from Flanders to the Netherlands. This resulted in a loss of valuable human capital—particularly from the cities—which was similar to what had happened as a result of the expulsion of the Jews from Spain, in 1492. As a result, the Netherlands achieved commercial supremacy, although their limited population meant that London soon became the leading centre for trade. It was in the British capital that the first institutions were created that promoted capitalism with a global vision. In was in this way that a project for global economic and commercial control was set in motion.

In summary, from the sixteenth century onward, the notion of the state had a major influence upon the power assumed by cities. In this sense, two traditions became consolidated within the territory of Europe. On the one hand, there was an area, which basically consisted of France, Spain, Portugal, England and Austria (Flora and Heidenheimer 2017), in which centralised states predominated. These imposed an urban hierarchy, whose summit was located in the capital. On the other, there was an area, which stretched from what is now the North of Italy to the Netherlands, via Switzerland and Germany, where the power of the cities was greater and was shared between various urban centres of similar importance. Professor Hohenberg (2004) referred to the antecedents of this second tradition in a very striking way:

> After the millennium, the pace of urban formation and growth accelerated in Western Europe. But while many towns were founded and grew, their distribution was far from uniform. By the 13th century, a clear pattern had emerged, with two cores near the coasts of the inland seas: the Mediterranean/Adriatic and North/Baltic. Linking the northern Italian and Low Country concentrations were a number of towns and urban-studded routes, from Paris in the west to central Germany in the east. Trade could flow in one or another of these network channels depending on the vagaries of war, the greed of robber-barons

> who controlled rivers and passes, the daring of bandits, and other market and non-market circumstances. At the external margin, a number of ports on the coasts of the inland seas funnelled the products of the interior for shipping to the core areas. Elsewhere, urban density tailed off as one moved east or west away from the core, and arable agriculture gave way to pasture, in a sort of macro-von Thünen pattern. In general, the south was more urban, more intensively settled, than the north, and the Italian core more developed than the Netherlandic one. (Hohenberg 2004: 13–14, on-line version).

It is a constant that in Europe, the main power, both at the local and regional level, has only been consolidated in areas where the presence of the state has been relatively weak. In the rest, the political hierarchy, with the capitals at the summit, has conditioned urban dynamics. In modern-day Europe, these traditions continue to be evident and have even been reinforced in states whose capitals not only concentrate the political power but also economic power (as in the cases of the United Kingdom, France and Spain, amongst others). Meanwhile, in other cases (such as the Netherlands, Germany and Italy), there is a much greater balance between dynamic and complementary cities, without the economic centre coinciding with the political one. Europe has therefore seen the configuration of an area which stretches from England to the Netherlands and to the north of Italy, in which the dynamics of the city system has stimulated the development of the regions within it. This is what is known as the city-belt. It is formed by city-states, whose origins date back to when the imperial cities were freed from the sovereignty of their princes. They form part of the city-belt, which since medieval times has formed a chain of industrial and commercial cities, extending from the Netherlands to the north of Italy. They have always been surrounded by quite large territories which, in the past, ensured them a supply of provisions.

This leads us to reflect upon how the limits between rural and urban space are established; this is a task that has grown increasingly difficult over time as the differences have become blurred. This has been the result of the way in which aspects of urban life have progressively invaded rural space and because the city now dedicates more of both its public and private space to nature. One reference in this respect is the garden city model put forward by Howard (1902), which has been developed and adopted in multiple variants.

The following section will be dedicated to defining key concepts such as the urban agglomeration. This is relevant for orientating the analysis of urban growth and interpreting the contents of Sects. 2.4, 2.5 and 2.6.

2.2 Defining Urban Space

Studying the limits of urban space requires prior reflection upon the terminology used, as this will directly affect the population data associated with it (Mojica 2011). One of the objectives of this chapter is to provide and use a series of urban population data for Europe between 1850 and 1950 and also for certain specific countries for later periods, up to 2010. Given that the data come from different sources, it has been necessary to homogenise them, as explained in Sects. 2.4 and 2.5. To achieve this comparative base, it was necessary to define the urban phenomenon as a continuous constructed space and to combine its analysis with that of official census data available since 1850 on the total population, which required municipal limits. These data were then organised in line with local units or municipalities in Europe, which had defined territorial limits. The municipalities are normally formed by a population nucleus and dispersed population. A municipality or local unit is considered urban once it passes a certain number of inhabitants (this threshold is normally 10,000). When we study urban units, this implies two problems that which we shall return to later because of their relevance. Firstly, as municipal population figures are totals for the whole municipal territory, they necessarily include both grouped and dispersed population. Secondly, when the nucleus expands and the built space units with that of a neighbouring settlement, the whole becomes an urban unit. This occurs even if the second nucleus has not reached the threshold necessary for it to be considered urban. In short, the data relating to local population will not always correspond to the reality of each urban nucleus. Solving this problem requires using the approach that I will define later.

Comparisons of population data made over time and between states therefore require an understanding of the implications of the *definitions* used by different official statistics organisms. Distinguishing urban from rural population is a necessity for states, as this makes it possible to optimise management of the territory. To do this, the definition of what is urban has to be adapted to the reality of each society, although this implies difficulties in wider studies of the type proposed here. In short, what is considered urban in one country would not necessarily be considered as such in another, but if we seek a comparative vision of Europe, unified criteria shall be applied.

It is necessary to begin with an understanding of the various definitions of urban population that have come from the academic and professional fields and that of public administration. The differences in criteria used to identify the urban space are a result of the characteristics of how they are populated in each country. They are also influenced by structural and functional changes that affect the territory, where the boundaries between the urban and rural space have become blurred. As a result, certain services and items of infrastructure have ceased to be exclusively urban. Hence, we find leisure centres and large commercial establishments in mountain areas, and there are dormitory settlements occupied by people working in the tertiary sector but who officially reside in traditionally rural municipalities. Similarly, there are large extensions of urbanised land destined for second homes. In short, the rural space is being urbanised.

Taking these aspects into account, it is possible to summarise the two main criteria for the classification and study of urban population in relation to how they affect any investigation on urban growth:

1. The quantitative criteria refer to the establishment of a minimum threshold for resident population in order to identify urban settlements. For the purposes of comparison, the problem stems from the fact that this threshold varies enormously between countries, from 200 inhabitants in Norway to 10,000 in Portugal and most of the other countries. Even so, this is the criteria that we will follow here, although we shall take into account.
2. The functional criteria, where we place the emphasis on the fact that urban zones can be differentiated by their labour structure and the services and functions that they offer. The sum of these functions defines the character of a location, whether that be urban or rural. Along these lines, it is frequent to find definitions that include a minimum number of services at the settlement and also the quality of the infrastructure.

For a qualitative comparison between states, we are interested here in considering whether urban agglomerations are clusters of intensely populated space whose population are stable over time. This focus is based on the continuity of the built space, even though there are often internal areas which are less densely occupied. The demographic criteria that we will use will therefore be flexible in terms of morphology and could include various urban forms, such as monocentric, polycentric and diffused settlements.

In summary, the urban space is a dynamic unit which has certain limits, which rarely coincide with the municipal administrative boundaries, particularly in the case of the largest agglomerations. Taking this into account allows us to examine the urban space from a historical perspective, referring to a single reference criterion, such as the built space, given that municipal borders also change.

The concept of urban agglomeration was adopted by the United Nations in 1978. It then recommended organisations responsible for compiling national statistics to follow its lead. As units for statistical reference, urban agglomerations refer to the contiguous de facto population of a continuously inhabited territory with a certain level of urban density, with independence of its municipal administrative limits. They normally include the population of a city and of its adjacent suburban areas (United Nations. World Urbanization Prospects: The 2007 Revision Population Database).

Given the fact that urban areas are dynamic and that, in general, they have tended to grow, the next section reflects upon the factors that allow us to understand their urban development.

2.3 Factors That Explain Urban Expansion

Cities are elements which have their own dynamics, but, at the same time, they are an expression of their national and international context. There are two fundamental indicators of their transformation, as we have already noted: the morphological expansion of the city and the growth of its population. As a result, the main primary sources that we use are, respectively, urban cartography and historical series for population. This information must allow us to measure the impact of the factors that are considered essential for urban expansion: the number of inhabitants and the extent of the built-up area during the period studied. In addition, we shall associate the geo-localisation of the urban area and its built-up area. Thanks to this, it will be possible to link certain essential parameters in order to evaluate the impact of the main factors that explain the urban dynamics, such as (1) the height and slope of the urban area and its surroundings; (2) its distance from the coast and the main infrastructure, such as railway lines and main roads; and (3) the evolution of the GDP of the region that it belongs to. In the following analysis, we will present our research; more information is available in Chatel and Moriconi-Ebrard (2018).

It is also significant to correlate the number of inhabitants of an agglomeration with its rate of population growth and territorial expansion, which are three interdependent variables. This has enabled us to examine various aspects, such as the extent to which the initial number of inhabitants in an agglomeration has influenced its subsequent growth. In the case of agglomerations of over a million inhabitants, it has been shown that this ceases to be a factor that attracts more population. A second conclusion from the analysis of these data is that, in Europe, agglomerations have expanded by an average of 78%, in terms of their total area, but only 33%, in terms of their total population, since the middle of the twentieth century (European Environment Agency 2007). This means that there has been a general decrease in population density. However, this type of study has not been carried out with a historical perspective at either the European scale or that of other countries. The reason for this is the previously cited difficulty involved in unifying sources for long-period data, which is something we shall discuss in the next section.

In a very different field, the factor of relief and slope is also crucial, as this may favour or complicate human activity, both relating to the founding of a city and carrying out economic activity or building infrastructure. This has meant that the majority of the population tend to live at low altitudes and especially below 600 m (Cohen and Small 1998).

On the other hand, a very short distance from the coast has had an evident attraction for population, especially along the Mediterranean coast of Southwestern Europe, since the

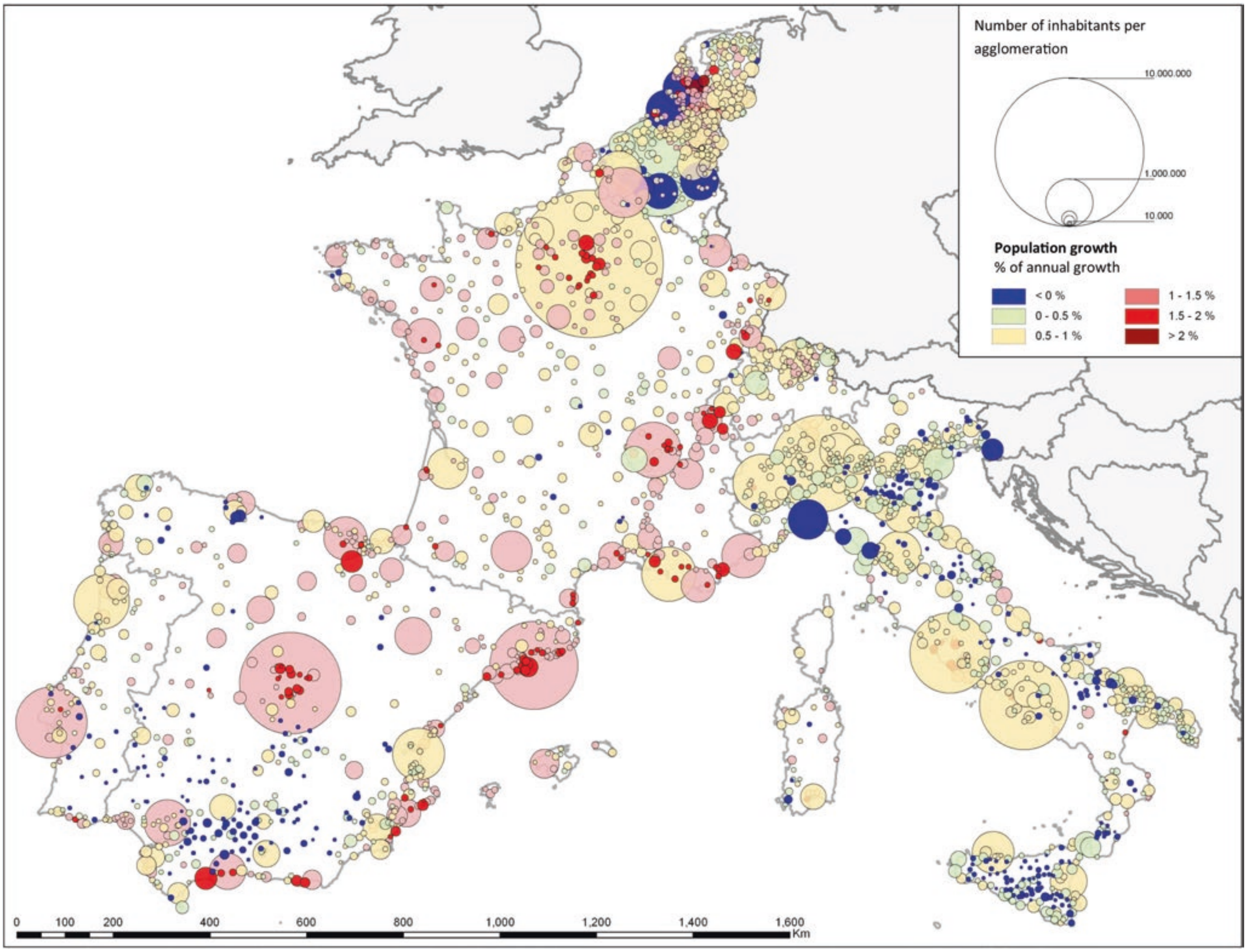

Fig. 2.3 The agglomeration formation process, 1950–2000

1970s. To be more precise, between 1960 and 1980, municipalities[2] near the Mediterranean grew by 0.9% more than those further from it. However, the municipalities near the Atlantic coast only grew by 0.4% more, in the same period. This process of population concentration along the coast, and especially along the Mediterranean coast, has come to be called "littoralisation".[3] An overview of the urban growth in this area can be checked in Fig. 2.3.

In the next section, we provide an overview of the literature and the sources available on the themes treated in this chapter.

[2]The study on which it is based refers to all the municipalities in Spain, France, Italy and Portugal, not just to urban agglomerations.

[3]The concentration of economic activity in coastal areas as a result of urban growth, industrial activities, tourism and irrigation

2.4 Sources for Population and Border Studies at the Local Level

As we have already mentioned at the beginning, the authors that have studied urban growth have taken two perspectives: quantifying changes in the population that lives in cities and studying their morphology, the space that they occupy and the characteristics of their dwellings and streets. It is not common to find works that combine both aspects and examine them from a historical perspective (see Alvarez-Palau et al. 2019 for cases in Spain) because of the complexity involved in putting together comparable information about morphology referring to a given territory over a wide timeframe. With this in mind, this chapter focuses on the first of these perspectives: it studies urban evolution in Europe, taking total population as its point of reference. This is an indicator of the dynamism and capacity to attract people looking for work which is commonly accepted. As a result, the growth of urban population tends to be used as a proxy for the historical study of economic development, at both the local and regional levels.

For an analysis of the evolution of cities within a geographical area like Europe, it is necessary to use a large database. The best source in this case is official censuses, which began to be common in European countries from the middle of the nineteenth century, with some precedents in Sweden, France, England and Wales and Scotland. However, the techniques, precision and contents of these censuses have always differed, both from country to country and within individual countries, despite efforts to coordinate such work, carried out by the International Society of Statistics from the nineteenth century. For this reason, the total information provided by censuses relating to economic and social questions are difficult to compile, compare and study for a large group of countries. Even so, the subject that concerns us here offers greater guarantees as it relates to counting population. Given that a person counts as an individual in any period or at any place in the world, it has been possible to carry out a comparative analysis of population at different scales: continental (Martí-Henneberg 2005; Chatel 2012), national (Chatel 2011; Martí-Henneberg et al. 2016), regional (Gregory and Martí-Henneberg 2010) and city level (Moriconi-Ebrard 1993; Bairoch 1988). However, what remains pending and what we also try to carry out in this chapter is a study of urban evolution which transcends municipal borders in order to analyse the real urban entities (Chatel and Moriconi-Ebrard 2018), rather than those separated by administrative borders, which are often arbitrary.

It is necessary to bear in mind the fact that the boundaries of local administration units were not conceived to delimit and manage urban areas. In Europe, the municipal structure has its origins in old ecclesiastical parishes. Later, the liberal revolutions of the nineteenth century gave rise to a new form of administrative organisation within the framework of a division of powers at three levels: municipal, regional and administrative and state. However, the differences between states are very large with respect to how this process of modernisation occurred and was reflected in administrative geography. The dynamics of each state have recently been studied comparatively, focusing on changes in their regions (Martí-Henneberg 2021). There have also been studies of the municipal level, although more from the perspective of political science and law. However, we are still needing to have all this information in GIS format and to use it to study the local administrative geography of Europe from the mid-nineteenth century through to the present day. This would make it possible to know the characteristics of each country and the extent of the reforms carried out to adapt to the management requirements of the welfare state since the 1950s. GISs, which reflect the evolution of local boundaries, are, for the moment, only available for England and Wales and Belgium, although they are currently being prepared for France (Litvine et al. 2020).

The type of municipal division is also important in this chapter, for two reasons: (1) the municipality is the territorial base upon which its population is quantified, and (2) it marks the boundary that separates two entities that could form a continuous built-up area and a single urban unit, which is the objective of our study. In summary, due to a lack of appropriate data, there have not been any previous detailed studies of the historical evolution of agglomerations in Europe, because the existing data all refer to municipal entities, although the urban reality has often transcended their boundaries.

2.5 A Research Agenda on Urban Growth, Combining Population Growth with Urban Morphology

This section presents a research agenda relating to urban growth. Then, in Sect. 2.6, we will offer some specific exercises along these lines because no generalised research into a territory as large as Europe has yet been prepared.

Research into urbanisation or urban growth is of analytical interest in itself and is also an accepted indicator of economic growth (Castells-Quintana and Wenban-Smith 2020; Cascio 2009). Quantifying the evolution of urbanisation in Europe over the past 170 years is a challenge that has yet to be fully met. The objective here is to define and quantify the part of the population that resides in urban agglomerations. These agglomerations consist of local units (whether single or grouped together) with populations of more than 10,000 inhabitants. Here, the new objective would be to present how to study the formation process of a continuous built-up area corresponding to real urban units that will then be compared. This objective involves the combined use of census data, a H-GIS of local units and data relating to the location of each municipal unit.

The main studies of urban history have largely been limited to certain specific scales: monographic, national and global, although there have also been a number of comparative studies. However, all these cases have been limited by the fact that they have focused on the central municipality of the agglomeration. If we take the example of Berlin from 1870 to 1940,[4] the problem is that the classical approach focuses on the tremendous increase in its population, but in fact it has to be explained by the aggregation of other municipalities to the central local unit of Berlin. Our objective

[4]Classical studies by Bairoch, Paul. Cities and economic development: from the dawn of history to the present. University of Chicago Press, 1991; Bairoch, Paul. The Population of European Cities from 800 to 1850: Data Bank and Short Summary of Results. Droz, 1988.

must consist of providing real comparisons that take into account the built-up area of each metropolis.

A new H-GIS database will therefore require a structure that can facilitate this new analysis of the urban phenomenon. Important urban areas have either tended to incorporate neighbouring municipalities in order to constitute bigger municipalities (as in such cases as Madrid, Barcelona and Paris), or on the other hand, each municipality has remained independent within a metropolitan organisation (as in the cases of civil parishes in the United Kingdom). Taking these two models into consideration, it is therefore important to insist on the fact that, when comparing urbanisation processes, it is not possible to primarily focus on municipalities. Instead, it is relevant to observe what has happened as they have merged and, if necessary, to reconstruct real agglomerations without taking into account administrative borders. The objective shall consist of first determining the present-day urbanised areas and then going back in time to reconstruct their evolution, based on population data for each of the municipalities that now form part of them. Figure 2.4 shows the case of Milan and its territorial expansion over time and how it absorbed what used to be neighbouring municipalities, during a first phase of expansion, and then created its metropolitan area.

Based on the previously cited information, it will then be possible to make an analysis of the evolution of cities, combining their areas of extension with population data in order to calculate their densities. In this way, it will be feasible to reflect upon their evolution and to compare them with dispersed cities, in different historical periods and different parts of Europe. It will also be necessary to complement this kind of quantitative study with some form of qualitative approach in order to check and correct our data, based on cartography and other sources.[5]

To accomplish this, a database on population at the municipal level shall be compiled to reconstruct and analyse the evolution of all settlements and, in particular, the most complex part: the creation and expansion of metropolitan areas since the beginning of the nineteenth century. To achieve this, two layers will be used: (1) the old municipalities, using X/Y coordinates for the central settlements, and (2) the boundaries of the current municipalities. By overlapping these two layers, it will be possible to identify which old municipalities are now part of the current agglomerations. After studying the formation of each agglomeration formation, we will be able to compare the urban dynamics in very different countries through their population and the area of its municipalities.

The feasibility of applying this methodology will depend on the detail of the spatial data contained in our database. Figure 2.5 provides a schematic view of the two main phases in the process of agglomeration formation. In the first of the three images, we see the initial situation (corresponding to 1850), in which a group of municipalities has a stable relationship with respect to a city (1) which structures its surrounding territory. In the second image, the local population has grown, particularly in the central city (1) and in the settlements closest to it (A). This population growth has resulted in the absorption of two municipalities (A) to form a single city, with an urban continuum; this situation was quite common in 1900. In the third phase (1950), urban growth continues, and more agglomerations are constituted, forming other nuclei (B); they are part of the same metropolitan area, but they have their own, independent, municipal character. This process took place in Europe from the 1950s with several antecedents in the largest cities.

The methodology used to decide which type B municipalities should be considered part of a given agglomeration is critical to this analysis. Although some of them may not have reached the population threshold of 10,000 inhabitants, they must still be considered nuclei of urban population. Research along these lines should take decisions based on a combination of factors: their total population, the rhythm of their growth (10% greater than the national average, for instance), the distance between them and the central nucleus (a distance of less than 200 m between built-up areas). This task would be carried out automatically with the aid of a new GIS application. The basic information required has already been compiled by Professor François Moriconi-Ebrard[6] and other authors, using old maps and CORINE Land Cover input for more recent periods.[7] Based on these criteria, we could make a new calculation of the territorial distribution of urban space within Europe.

This methodology would improve the current state of the art, whose criteria are good for writing monographs but do not permit a more general vision involving the use of comparable data. To date, we have had to depend on the different criteria used in each country to decide what constitutes an agglomeration. As a result, until now, long-term transnational comparisons have not been possible. Another methodological problem found in the literature is that the calculation

[5]Solanas, Jorge; Alvarez Palau, Eduard; and Martí Henneberg, Jordi. "Estación ferroviaria y ciudades intermedias: lectura geo-espacial del crecimiento urbano mediante indicadores SIG vectoriales. El caso de Cataluña (1848–2010)." GeoFocus, 16 (2015): 253–280.

Gregory Ian N. The accuracy of areal interpolation techniques: Standardising 19th and 20th century census data to allow long-term comparisons. Computers Environment and Urban Systems 26 (2002): 293–314.

[6]Research program Europolis: http://e-geopolis.org/programmes-de-recherches/europolis/

[7]Zdanowska, Natalia. "Metropolisation and the evolution of systems of cities in the Czech Republic, Hungary and Poland since 1950." Deturope–The Central European Journal of Regional Development and Tourism 7.2 (2015): 45–64.

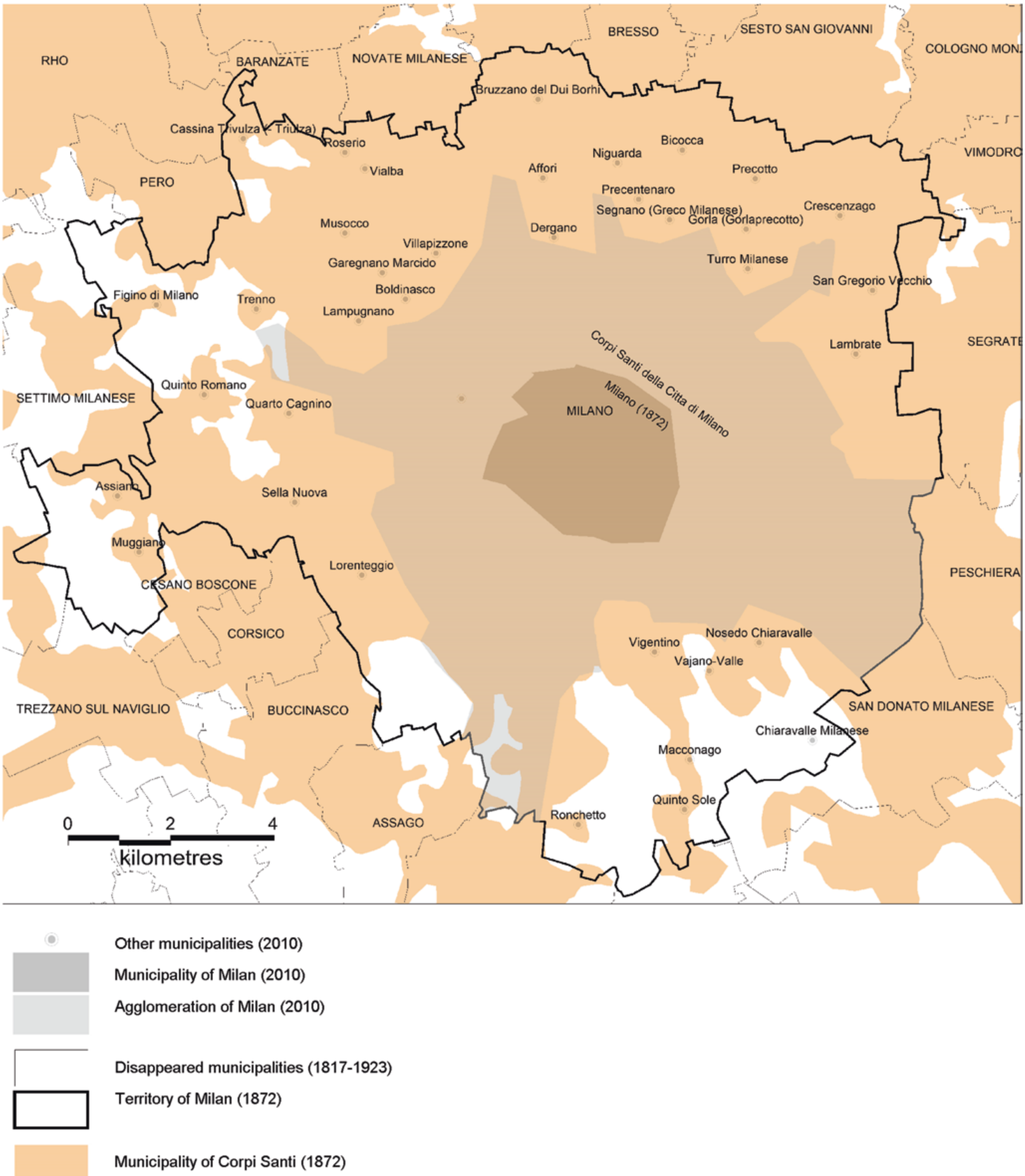

Fig. 2.4 The expansion of Milan. (Source: eGeopolis, François Moriconi-Ebrard)

of the urban population has mainly been based on municipalities that existed at a given time, but with only those with populations of more than 10,000 inhabitants being considered. When these criteria are applied over an extended period (as in the quoted work by Hohenberg and Lees 1995), there is a tendency to erroneously focus on sudden increases in population, which do not necessarily indicate the presence of more people in a given area but rather the aggregation of

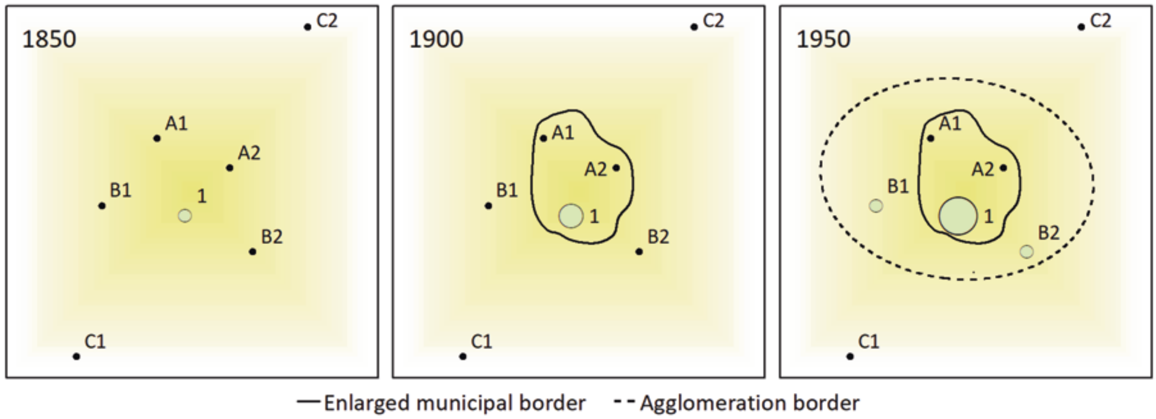

Fig. 2.5 The process of agglomeration formation in SW Europe

smaller units close to the central city. As we have already seen, this occurred in the case of Berlin, but it has also happened in many of the other cities analysed, such as Milan.

In the case studies in the following section, it will be necessary to clearly illustrate the issues that have been previously discussed.

2.6 Case Study: The Quantification of the Agglomerations

In this section, we shall study the 1607 municipalities/agglomerations that had reached populations of at least 20,000 inhabitants by 1950.[8] The sources of this information were the population censuses provided by all of the countries which produce total population related to the municipalities in which the cities are located (Fig. 2.6).

As indicated in the previous section, this is where the first controversial issue arises to two aspects which are difficult to combine: (1) a political reality such as that of administrative division, which are municipal in this case, and (2) the reality of continuous built-up space. As we know, the problem arises when the reality of an urban agglomeration stretches out beyond its administrative limits; it is then that decisions need to be taken as to how to describe and quantify the urban area in question. The pluri-municipal space that it occupies influences the calculation of the population that is considered urban and the very conception of what is urban. In the period from roughly the end of the nineteenth century to the first third of the twentieth century, the solution which was generally adopted for the management of rapidly growing cities was to absorb their neighbouring municipalities. Then, throughout the twentieth century, not only did central cities grow but also those around them, which already had clearly defined personalities. As a result, metropolitan areas, of the type that characterise modern-day Europe, have gradually developed over time.

Taking these 1700 agglomerations into account, we shall finish this chapter by presenting some of the calculations that can be made based on these data. At the European scale, an exercise has been conducted which consisted of calculating the potential attraction between agglomerations in a territory as large as Europe. This same exercise can be applied to a vision of a whole set of data, such as that relating to priority transport infrastructure. Figure 2.7 shows this potential and its historical evolution (1870, 1910 and 1950).

Figure 2.8 shows these same values at a more detailed scale in an individual country; in this case, Spain.

2.7 Tutorial

The phenomenon of urban population is one of the most studied themes in geography and demography. There is abundant bibliography about it (Moriconi-Ebrard 1993, 2000). Here, we will examine the theme from three different geographic perspectives. We will always do so using geographic information systems as a tool of analysis.

1. We will calculate the accumulated annual growth rate (AAGR) between 1940 and 1950 for several different urban municipalities. With the result, we will then generate a map. With it, we shall see which are the cities that have grown most and which have lost population.
2. We will calculate the—straight line—distance between the municipalities and the railway network.
3. We will calculate the percentage of rural population.

We will work on all three municipalities at the European scale. However, the procedure can also be applied at the regional scale, which makes it easier to observe regional disparities in this variable.

[8] Although it is necessary to take into consideration the fact that various authors writing about urban history (Bairoch 1988) have also included the urban history of all nuclei with more than 2000 inhabitants through their studies of Europe

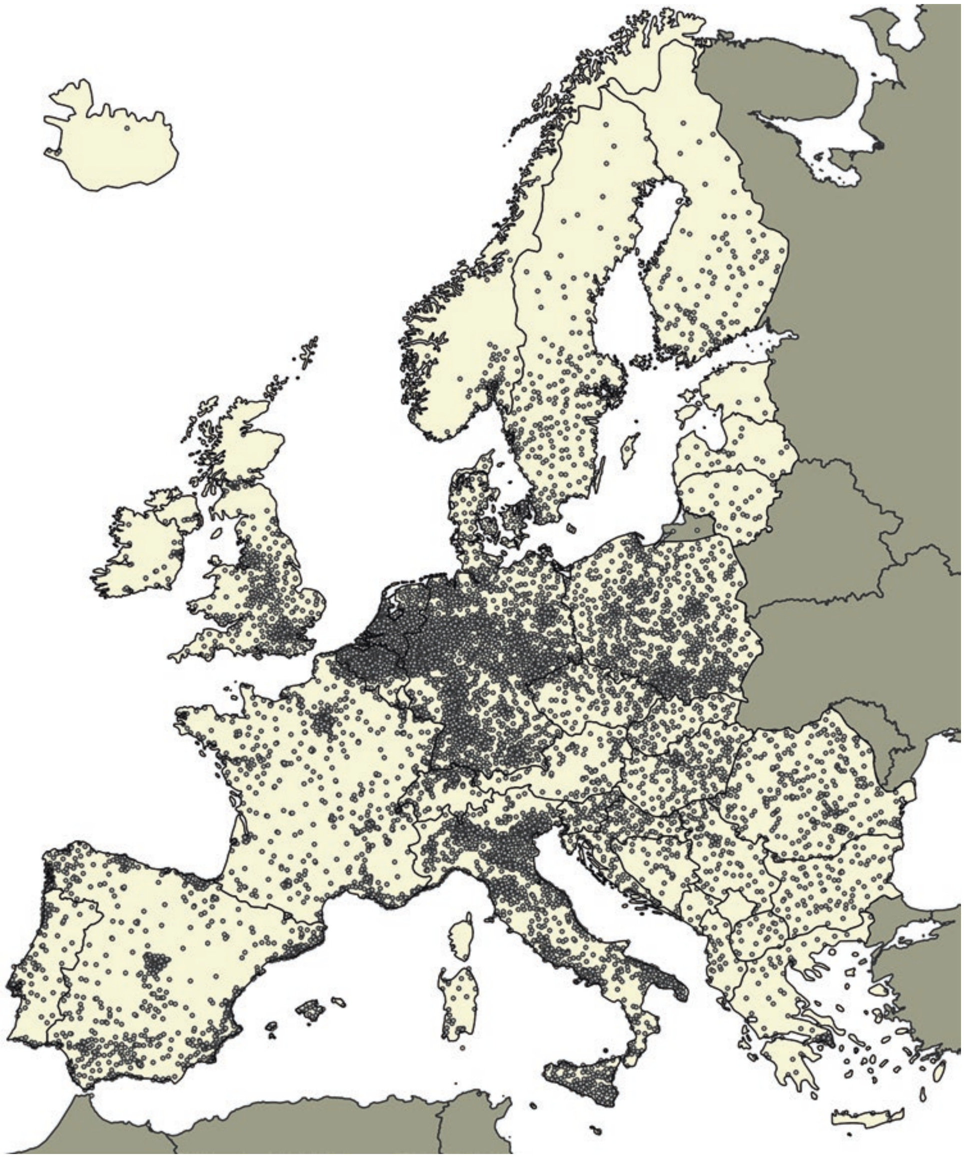

Fig. 2.6 The urban network of Europe (> 20,000 inhab. in 1950)

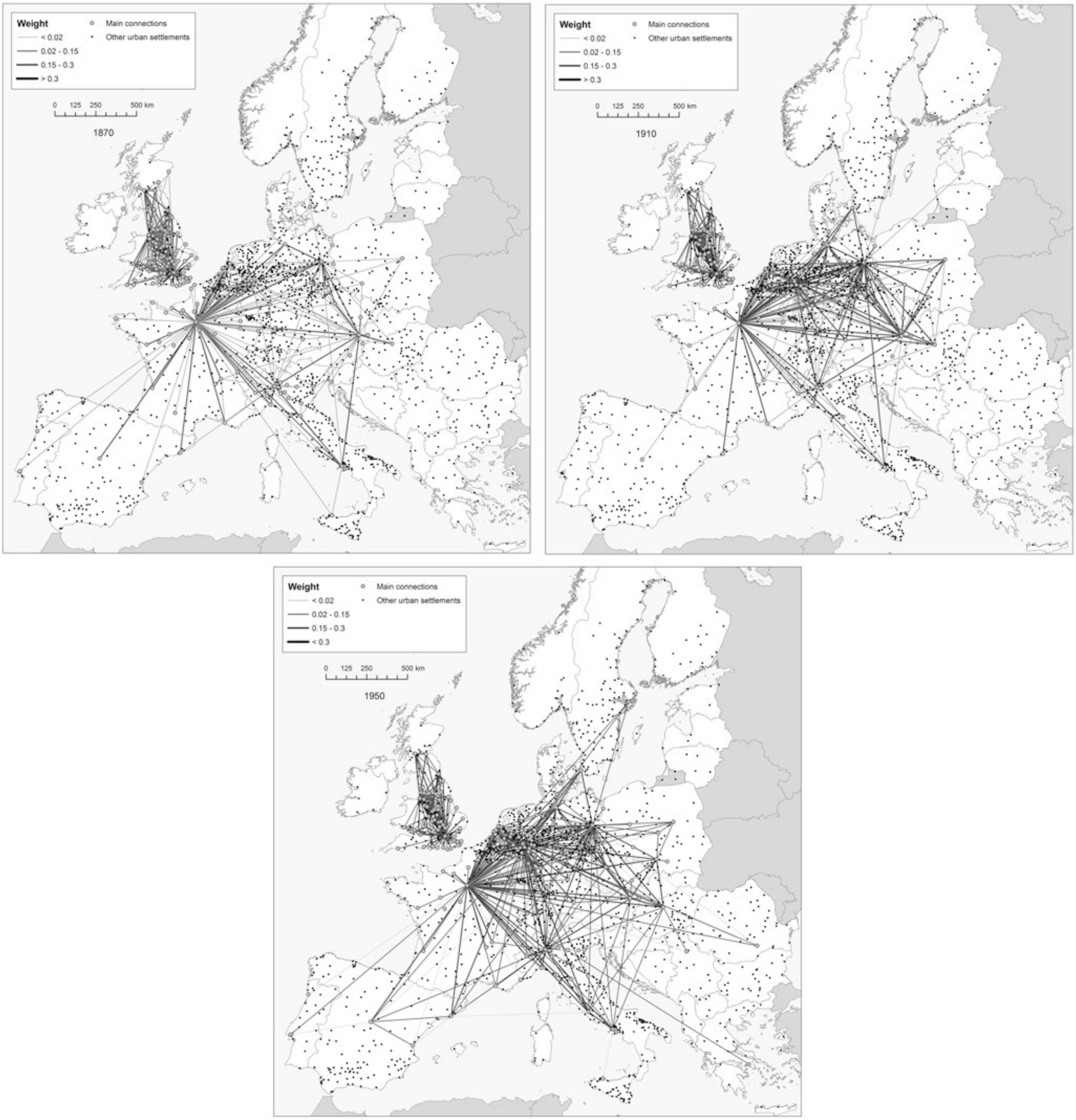

Fig. 2.7 Quantifying the attraction intensity between urban areas in Europe: 1870, 1910, 1950 (Source: San-José, Adrià)

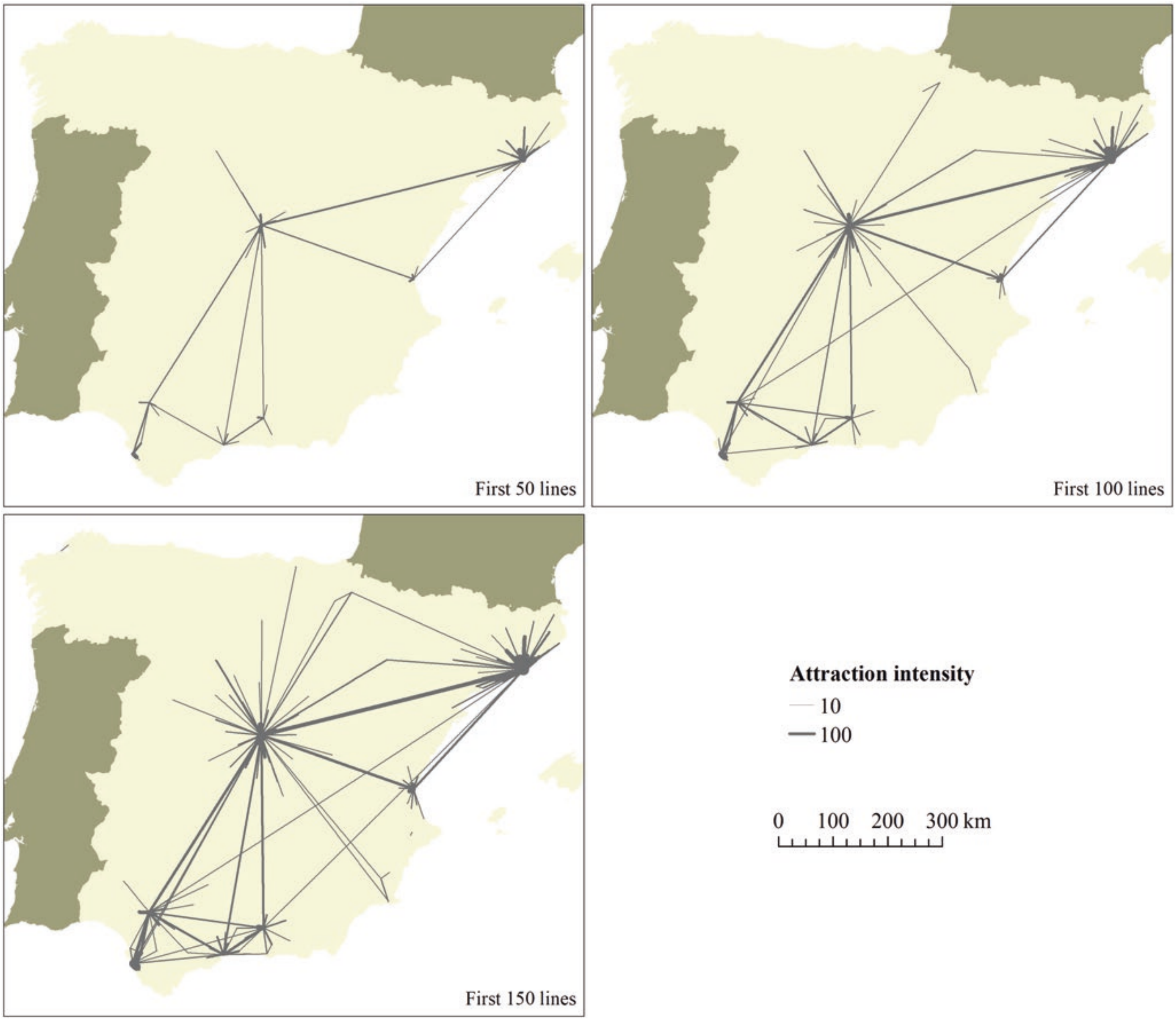

Fig. 2.8 Quantifying the levels of attraction intensity between urban areas in Spain: 1870 (Source: San-José, Adrià)

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Roads and Waterways: The First Inland Transport Systems and the Subsequent Major Impact of Road Transport

3

Jordi Martí-Henneberg

Abstract

In the 1830s, railway lines began to replace waterways and stagecoach systems as the means of connecting cities, harbours and industrialising regions. At the same time, regional and local governments started to pave the roads used by horse-drawn vehicles in order to create a feeder system for the rail network and to accommodate increased traffic caused by industrialisation.

Transport infrastructures have been increasingly seen as a practical way to make European integration a reality. The construction of integrated transport networks is not only an economic and social need but also a political project. In a famous speech before the League of Nations' tenth assembly on 5 September 1929, the French foreign minister Aristide Briand revealed his dream of a political federation of European states.

This chapter will include H-GIS at two levels: the European scale, based on a database of main roads in Europe from 1835 on, and the national scale, which will include a new H-GIS for Spain of not only the main roads but also the secondary and tertiary levels for years 1861, 1887, 1912, 1940, 1963 and 1999.

Keywords

Roads · Waterways · Europe · H-GIS

This study of the development of the main roads and inland navigable waterways in Europe has been unified in this chapter because these were the two main forms of transport used during the pre-Industrial Age. Although their evolution, through to the present day, has been very different, they have shared a common challenge: both had to compete with rail transport when this new mode of transport appeared.

Although modifications of all types of transport tend to be considered positively, and seen as signs of progress, in the case of road transport, there have also been negative consequences. There have basically been three of these: pollution associated with massive-scale motorisation; motor vehicles occupying large areas of public space in cities; and the development of a dispersed city model which consumes lots of territory. However, every new problem also—almost inevitably—tends to generate new solutions. In this case, these have included the promotion of public transport and improvements in inter-modality amongst the different means of transport. Looking to the future, the consolidation of the electric car and of car-sharing should bring further improvements, but this is not a subject that we will discuss here.

In this chapter, we will consider two central themes. The first, which will be examined in the first two sections, relates to the historical evolution of road infrastructure and that of inland waterways. The second, which will be discussed in Sects. 3.3 and 3.4, is a reflection on the impact that the emergence of road transport—which has played a fundamental role over the past 70 years—has had on our territory and society. Here, we seek to study some of the key characteristics of the evolution of transport infrastructure and to relate them to the abusive development of private transport. Finally, and in line with the general focus of this book, in Sect. 3.5, we will present a number of didactic themes and lines for further research. It will be possible to study these, thanks to the data that we have provided in GIS format.

Despite the criticism that this chapter makes of the negative impact that road traffic has in modern-day Europe, I would like to stress that this is not a publication that is against road traffic; in fact, just the opposite is true. A future com-

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bined model for transport must include the car, but limiting its use to what is strictly necessary while, at the same time, improving the supply of collective transport.

What is more, it should be added that the heritage and historical components of old roads tend to be increasingly valued. Although this is a subject that will not be treated here, there is now a flourishing line of research into the recovery of inland waterways (Nasiri et al. 2019) and historic roads (Navas 2017) as elements that form an essential part of our heritage. Furthermore, the network of secondary and local roadways is essential for promoting a balanced distribution of population within a given territory. This chapter is closely related to Chap. 1, about borders and population; Chap. 2, about urbanisation; and Chap. 4, about railways.

3.1 Considerations Regarding the Historical Relevance of Inland Waterways and Roads and the Absence of an Inter-modal Perspective

The historical perspective promoted by this book allows us to verify the antecedents to the problems that our society is currently facing. Here, we refer to the uncontrolled growth of road transport with respect to other modes of transportation. The perverse effects of this reality are not only environmental in nature; they have affected the quality of life enjoyed in cities and resulted in a disorderly expansion of the built-up space. In this section, we present several antecedents which are relevant for interpreting this reality.

In the study of the process of the modernisation of transport, one factor that is at least as important as the provision of transport infrastructure is the organisation of the services that use it and provide its traffic. For this reason, this section is dedicated to some considerations regarding the role played by transport services and their importance for economic thought, taking Adam Smith as a reference. The importance given to transport by the world of economics has been maintained through Paul Krugman and other modern contributions within the field of the "new economic geography".

In Europe, numerous transport companies, haulage firms and shipping lines were independent operators and, for centuries, offered their services using carts, stagecoaches or river boats. From the mid-nineteenth century onwards, however, these traditional systems began to face strong competition from railways. Yet, far from disappearing, they adapted to the new circumstances, offering complementary services, often based at the railway stations themselves. With the aim of gaining travellers, the railway companies mainly operated from cities and centres of production and also near river and sea ports (Alvarez-Palau and Martí-Henneberg 2020). The railway network became very dense in some regions, but the number of access points—the railway stations—remained limited due to the high cost of investment and maintenance. The main limitation on the railway as a form of land transport has always been its incapacity to provide a door-to-door transport service. For this reason, designing a combined transport system based on inter-modal cooperation has always seemed the best solution (Fig. 3.1). However, putting this into practice has always been complicated due to the diversity of the many actors involved: owners of infrastructure, service managers, political powers responsible for passing associated legislation and local interests, amongst others.

If we take a look back into the past, we see that despite the modernisation and consolidation of a diversified offer of transportation, in the course of the nineteenth century, the challenge still remained the same: how to move goods and people between two different points, as efficiently as possible. This normally called for more than one mode of transport. Adam Smith set a precedent by underlining the importance of the quality of transport services for economic growth. Although he did not explicitly refer to the idea of inter-modality, he referred to the three main systems of internal transport, adding that they were indispensable for breaking monopolies and helping promote economic growth. He subsequently had a decisive influence on both economic thought and practice. Indeed, it is relevant to focus on his memorable text in order to understand the function of transport within the economic model that he advocated. In the following passage, Smith primarily referred to freight transport and to improving it as a way of making it a transforming agent and helping to achieve a liberalised economy:

> Good roads, canals, and navigable rivers, by diminishing the expense of carriage, put the remote parts of the country more nearly upon a level with those in the neighbourhood of the town. They are upon that account the greatest of all improvements.[1]

In the following passage, he explained the importance of improving the role of transport in economic life and, more specifically, in defending an economy based on free competition. As a result, in contrast to monopolistic practices:

> They [roads] encourage the cultivation of the remote, which must always be the most extensive circle of the country. They are advantageous to the town, by breaking down the monopoly of the country in its neighbourhood. They are advantageous even to that part of the country. Though they introduce some rival commodities into the old market, they open many new markets to its produce. Monopoly, besides, is a great enemy to good management, which can never be universally established but in consequence of that free and universal competition which forces everybody to have recourse to it for the sake of self-defence.

[1]This and the following texts are taken from *The Wealth of Nations*, Chapter XI: On the Rent of Land Part I: On the Produce of Land, which always affords Rent, from page 149.

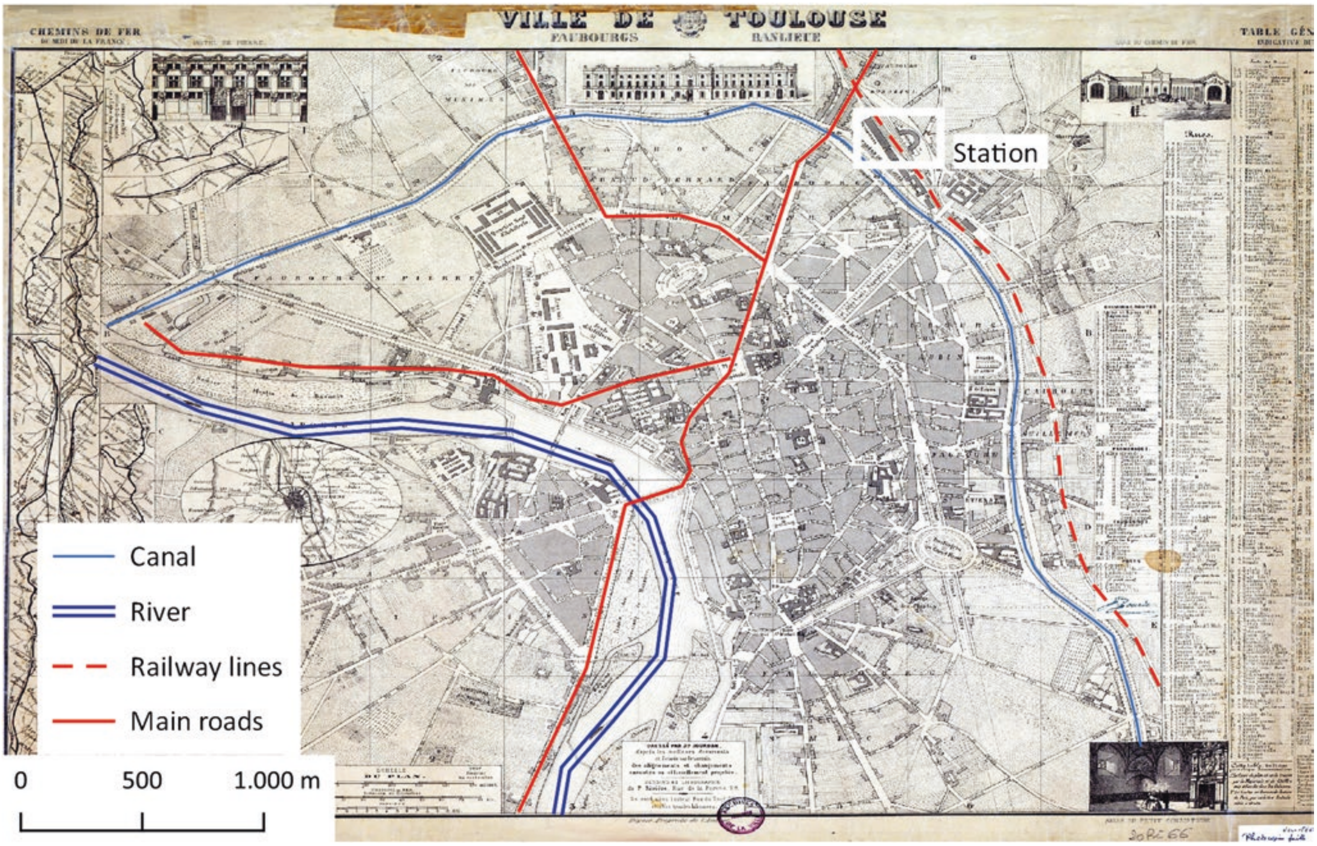

Fig. 3.1 Railways, canal and river in Toulouse. (Source: own research from Jourdan and Rivière 1860)

He then went on to provide a telling example of the divergence of interests that improving transport systems could produce:

> It is not more than fifty years ago that some of the counties in the neighbourhood of London petitioned the Parliament against the extension of the turnpike roads into the remoter counties. Those remoter counties, they pretended, from the cheapness of labour, would be able to sell their grass and corn cheaper in the London market than themselves, and would thereby reduce their rents, and ruin their cultivation. Their rents, however, have risen, and their cultivation has been improved since that time.

Smith did not say much more about transport in the course of his work, but these paragraphs have served as the basis for defending and developing the idea that the efficiency of the means of transport favours free competition by broadening markets.

This greater competition, from a new road (Bogart 2005) or canal, influenced the demand for alternative products. For example, as Satchell (2017) observed, "When buyers had a choice of raw materials – such as wood, peat and coal – the availability of cheap carriage via a navigable waterway could determine which commodity was used. Coal, for example, could not be sold profitably if it had to be transported more than fifteen miles by road; consequently, waterways massively increased the relative competitiveness and consumption of coal when it had to be transported over long distances".

Access to waterways was also closely related to urban growth. It should be remembered that the conditions for using a navigable river, or opening a new canal, are much stricter than those for opening a new road. It is necessary to have a continuous, stable and sufficient flow of water and, in addition, for this to run over relatively flat terrain. For this reason, waterways require considerable investment in construction and maintenance, and they can only be promoted in areas where there is an important level of supply or demand, such as in cities, ports and mining areas. The options for making these types of investment under favourable conditions were relatively limited within a given territory. It has been shown that the availability of waterways and sea transport encouraged the presence of urban nuclei. This can be seen in Table 3.1, relating to England and Wales in 1831. Of the 433 cities at that time, 218 were already connected by inland waterways, 28 by sea and 84 by both.

It must be remembered, however, that having a good endowment of a specific mode of transport was not, in itself, sufficient to ensure an appropriate connection between the points of origin and destination. This has been demonstrated

Table 3.1 Urban size and proximity to waterways and the sea. England and Wales, 1831

Towns and cities 2 miles from a navigable waterway or the coast	Population	Near waterways	Near coast	Near both	Not near either	Total
1	2000–10,000	162	20	64	99	345
2	10,001–25,000	33	5	14	4	56
3	25,001–50,000	13	1	2	–	16
4	50,001–100,000	6	–	4	–	10
5	>100,000	4	2	–	–	6
Total		**218**	**28**	**84**	**103**	**433**

Source: Satchell, Max. 2017. Navigable waterways and the Economy of England and Wales 1600–1835. *The Online Historical Atlas of Transport, Urbanization and Economic Development in England and Wales c. 1680–1911*.
https://www.geog.cam.ac.uk/research/projects/transport/onlineatlas/waterways.pdf

by studies of the evolution of the quality of market access (Bogart et al. 2017) from any point in a given territory, which include and quantify the combined effect of all the means of transport available. However, studies of the history of transport have tended to adopt a predominantly unimodal perspective, which, according to Donovan, needs to be enriched by another multimodal type of study: "Change in the present creates pressure to re-examine older accounts of the past (…). It is time that historians of transportation begin thinking outside the modal box" (Donovan 2000: 4). I insist on inter-modality[2] because I think that we have so far missed the opportunity to take into account its importance over the course of modern history. The shortcomings of this omission have persisted until today, as this is the main difficulty encountered when promoting the use of public transport. It is evident that the railway improved transport, yet only between stations. As a result, the train has always needed paths and roads to finish its routes. The advance that the railway implied was therefore very substantial, but still insufficient. A capillary system was needed to reach all of the corners of a territory and its cities. Waterways and roads also adapted to the requirements of the industrial revolution, but their trajectories were very different. Investment in waterways practically ceased when investors focused on railways instead, due to their future potential. However, thanks to their low maintenance costs, canals were not abandoned (Kunz 1992). The current network is similar to that of the nineteenth century, as we shall discuss later though changes have been calculated (Werther et al. 2021) The largest rivers and canals currently maintain (Radmilovic and Maraš 2011) stretches which are relevant for intensive use for the transportation of merchandise. On the other hand, the narrowest ones offer tourist services which can be enjoyed using pleasure boats.

The next section provides a general overview of the development of inland waterways and main roads of Europe.

3.2 The Historical Development of Inland Waterway and Road Networks in Europe

In this section, we present the evolution of inland waterways and roads. These were the means of inland transport that had the widest presence over the course of history, prior to the arrival of railways, but they have tended to be analysed separately within the historiography available. The general bibliography relating to roads across the whole of Europe (Lay 1999; Livet 2003; Schiper 2008) and that relating to navigable waterways (Kunz 1992) constitute two different fields. However, according to a more recent study of transport in England between 1760 and 1830, when complementarity between the two modes of transport was achieved, the whole system exhibited increasing returns (Bogart 2005). For this reason, it is necessary to stop analysing their effects separately and, instead, to study them from the perspective of their inter-modal cooperation. Looking to the future, insisting on this approach will facilitate the development of a culture of cooperation between institutions and companies, which is an area with few examples of good practices.

If we look at infrastructure, it is necessary to start by taking into account the restrictions associated with the construction of both means of transport. Firstly, there is the navigability of waterways, which require a territory that is relatively flat and with abundant water. If we take into account differences in orography and rainfall across Europe, this explains the majority of the territorial inequalities in their distribution.

[2] One good example of the concern for inter-modality that already existed in the nineteenth century can be seen in the *Atlas des Ports de la France* (Ministère des Travaux Publics). List of ports: https://biblioteca.mmb.cat/portades/22313.pdf). This was a collection of 166 monographic maps of each port, at the scale of 1:50.000, which was published between 1871 and 1897. The central theme of the collection is the morphology of each port and its urban area and the provision of complementary infrastructure at the port: rivers, canals, paths, roads and railways. Each map provides details of great value for managing the complexity of port traffic, which are quintessential inter-modal nodes. This is a source of great value and one endowed with cartography that provides an impressive degree of detail.

The function of European canals was to connect points of special relevance. Their use and the development of the first canal projects was therefore initially in largely independent and self-contained sections. It was only later that they were planned as a network. One added problem associated with canal transport was the high cost of trans-shipment, which could not be carried out on platforms, as in the case of rail transport. Even so, in England, the canals were generally profitable (Satchell 2017: 33). It was only competition from railways that limited investment in waterways, although the majority remained available and in service due to their low maintenance costs.

There is, as of yet, no comprehensive and comparable study of inland waterways in Europe with a historical perspective. The studies available (Kunz 1992), combined with other scattered references, show that the construction of canals for irrigation purposes has a very long history. However, if we look at their use for transport, the first navigable canal in Europe was constructed in the twelfth century to carry the marble required to construct the cathedral of Milan. The route included part of the River Ticino, which the Naviglio Grande Canal followed for 50 km. Other stretches of canal were constructed as and when required, but the idea of forming an integrated network only arrived in the seventeenth century, with the Briare Canal (1642), in France, which connected the rivers Seine and Loire. The construction of the Canal du Midi (1681), which connected the Mediterranean Sea to the Atlantic Ocean via 240 km of a new waterway, between the rivers Aude and Garonne, was a much greater task. In Great Britain, the first canal was promoted by the, surprisingly aptly named, Duke of Bridgewater. This was inaugurated in 1871 to transport coal to Manchester from the duke's mines.

The construction of canals in Europe was complemented by investment to extend navigable stretches of rivers and thereby create integrated networks. This was the result of strategies designed in each country at the national level, whether as public initiatives (as in France) or with private capital (as in the United Kingdom). As already noted, there were basically three essential prerequisites for developing a network of navigable waterways: extensive areas of flat land, a sufficiently large water supply and a consistent economic activity to justify the investment. These conditions were only met in certain areas of Europe: in much of France and the United Kingdom, in the Netherlands and in the—at the time—independent territories which now form part of Germany. In Fig. 3.2, it is possible to observe the waterways of France and Germany, where there was a sufficient level of complementarity between navigable rivers and canals to form an extensive network. Having efficient transport networks at the beginning of the nineteenth century helped both countries consolidate the first Industrial Revolution in these areas.[3] In contrast, countries on the periphery of Europe, in the Balkans and on Mediterranean peninsulas found themselves in a very different position. Spain, for example, did not have any of the three conditions previously highlighted. As a result, the country had to survive, as best it could, with a poor road network until a railway network was eventually established. This began in the 1850s and was later largely driven by foreign investment.

The subsequent stagnation in investment in canals can be explained by the advantages offered by rail transport. These included being able to overcome the restrictions of topography, very cold temperatures and the availability of water imposed on building canals. In contrast, the railway offered punctuality and speed throughout the year and over the whole national territory.

In the case of roads, it is important to highlight that they have been a reality since human societies first established fixed settlements and found the need for permanent thoroughfares. Given their capillary distribution throughout a territory, this was—and generally remains—the best way to meet the need to move between any two points. The oldest, and perhaps most spectacular, road network was that established by the Roman Empire. Its main function was to facilitate the movement of troops and to thereby ensure effective control over Rome's vast possessions; this called for a good system of land transport. In this way, Rome differed from other Mediterranean powers, which had geographically scattered colonies and whose main, and indeed basic, means of communication were maritime. Establishing the nature of the cause-effect relationship which existed between the road network and the distribution of cities in the Roman Empire is one of the many themes that have yet to be totally resolved. One relevant question relates to what was decided first: the structure of the future network or the locations—whether existing or foreseen—of its cities and strongholds. Another question concerns whether everything always followed a given pattern or depended on the circumstances of each region. Several recent works have cast a little light upon these issues (Carreras and De Soto 2013; De Soto 2019). Although there are no direct primary sources to provide numbers and information about the distribution of the urban population in Roman cities, several very valuable approximations have been published (Zorn, 1994. Carreras 2014). Similarly, we may ask ourselves what knowledge those managing the empire really had about their own territory. Here, it is significant to pick up on the introductory comment that Mary Beard made in her work SPQR, which could be equally

[3] In the map series shown at https://europa.udl.cat/projects/inland-waterways/, it is possible to observe the situation in 2001, which does not differ greatly from that of the twentieth century. The differences between countries in the endowment of infrastructure are considerable. For a more up-to-date vision, see Činčurak and Biljana (2019).

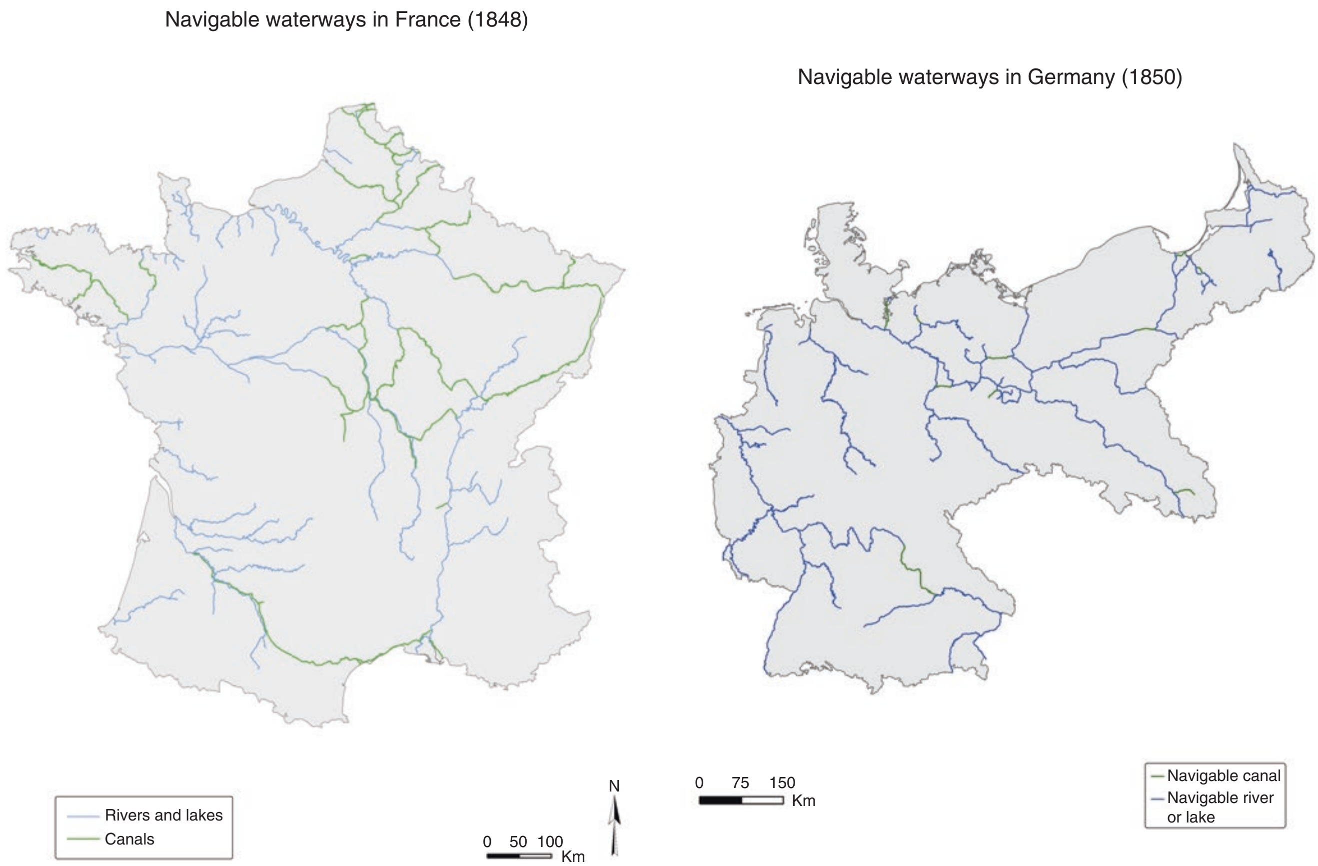

Fig. 3.2 Navigable waterways, France and Germany

applied to our current knowledge about the empire's conception of its territory:

> Roman history is always being rewritten, and always has been; in some ways we know more about ancient Rome than the Romans themselves did. Roman history, in other words, is a work in progress. (Beard 2015, Introduction)

The historical study proposed here has enabled us both to adopt a very detailed global perspective and to construct GIS maps in unprecedented detail. This interest in analysing the road network in GIS format, highlighted in this chapter, has also allowed us to study its evolution and relationship with other elements within a territory, such as its cities and ports and other means of transport.

Applying this approach to the whole of Europe (Zhou et al. 2019; De Soto and Carreras 2021; Vitale et al. 2021), it has been possible to study the evolution of accessibility to transport by mapping both the Roman Empire and the situation in the Middle Ages. The resulting maps show that the transport network has changed greatly over time. For the Modern period, other approximations have been made that have enabled us to perfect many of the techniques used in network analysis, albeit only in certain specific countries, such as the United Kingdom (Bogart et al. 2017) and Spain (Pablo-Martí et al. 2021).

This limitation has been due to the fact that there are no historical databases about roads in Europe. The basic problem here is that each country uses its own classification system for distinguishing between first- (Fig. 3.3), second- and third-order (Fig. 3.4) roads. As different countries do not follow the same criteria, making comparisons between them is a very complicated task. Below, we present an exception to this general rule: the evolution of the motorway system. This is the category which best lends itself to comparisons, as these are always rapid transport routes, with a minimum of two lanes of traffic in each direction.

A recent investigation has produced a GIS for motorways in Europe. This shows both their origins, in 1925, and their rapid densification from the 1960s onwards. This tended to start in the most developed countries and was then followed, through a subsequent "catching up" process, in the more peripheral ones. This study[4] has involved the digitalisation, in GIS format, of the evolution of motorways in Europe, from the 1920s through to the present day. In the tutorial,

[4] http://www.studiofolder.it/european-motorways/

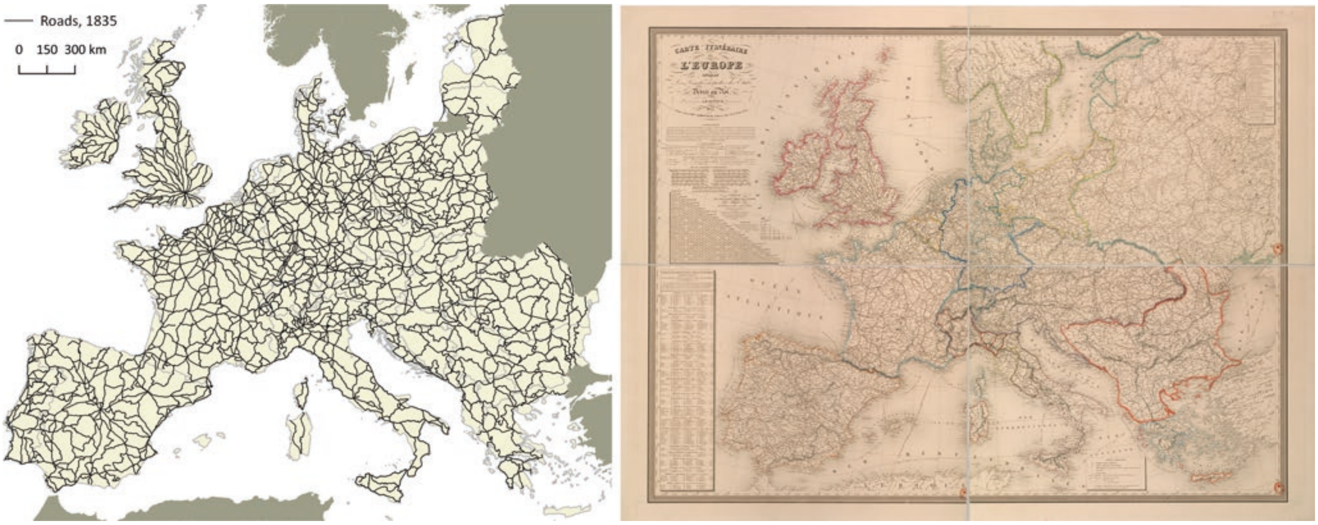

Fig. 3.3 Main roads, 1835. (Source: Own research and Dufour 1835)

these questions are explained in greater precision, particularly in exercise 2.

When making a historical study of transport infrastructure, it is necessary to highlight the fact that—together with navigable rivers and ports—roads are the type that has had the greatest permanence over time. Even so, technical advances in locomotion have forced road transport to continuously readapt. For example, it was the invention of the internal combustion engine and of the rubber tyre that opened the way for the current importance, and indeed dominance, of motor vehicle traffic. Thus, the old tracks and roads were replaced by a new, manufactured product, which was characterised by the massive use of tar, and major roads were specifically designed to interconnect the main centres of production, commerce and population.

Over time, states assumed increasing protagonism in the creation of road networks. In Europe, there were two models for the organisation of the main national road network: the centralised model and another which took the form of a mesh. Countries with centralised plans for their national road network made their capital its point of origin. In France, this point of origin is just in front of the cathedral of Nôtre-Dame; in Spain, it is in Madrid, at the Puerta del Sol. This organisational logic made little sense in countries which were less centralised. The other tendency could therefore be found in countries like Germany and Italy, which had only recently been united, where the national road networks were based on the needs of a set of states and cities that each had great relevance of their own. This also explains why their respective capitals have never had a predominant role, with respect to other major centres, in the design of their national transport networks.

In Europe, the road network of each country responds to its own historical logic. It is therefore difficult to speak of a European network of roadways. Where there are cross-border connections which have made it possible to interconnect national networks, this is because the states concerned came to agreements and built border crossings that allowed their control and facilitated the movement of merchandise, after payment of the customs duty charges.

The evolution of the quality of factory-made roads was associated with the development of completely new transport artefacts, such as the internal combustion engine for cars, lorries, coaches and motorcycles. The exponential growth of its use in the course of the twentieth century helped it to reach all corners of the territory, with the sole exception of certain high-mountain areas. However, this unquestionable technical advance has not been exempted from a certain degree of controversy due—as is often the case—to its abuse. The number of vehicles in circulation in the world has grown exponentially, and Europe has not been an exception. Table 3.2 presents the number of private cars (PC) and commercial vehicles (CV) that were on the road in European countries between 1900 and 2018. It can be seen that the period with the greatest acceleration in their use was that between 1960 and 2018, although the indicators were initially more modest in countries such as Greece, Hungary, Poland, Portugal, Spain and Yugoslavia. In other words, the countries which began their economic take-off earliest saw a parallel increase in the growth of their motor vehicle fleet. By the 1990s, however, all of them had reached very high per capita levels.

The motor vehicle fleet that uses this infrastructure has always exhibited a high degree of complementarity between private initiatives and those of the public sector. The manufacturing of motor vehicles was the result of private initiative, while the state took the lead in constructing roads, extending and improving the road network and regulating

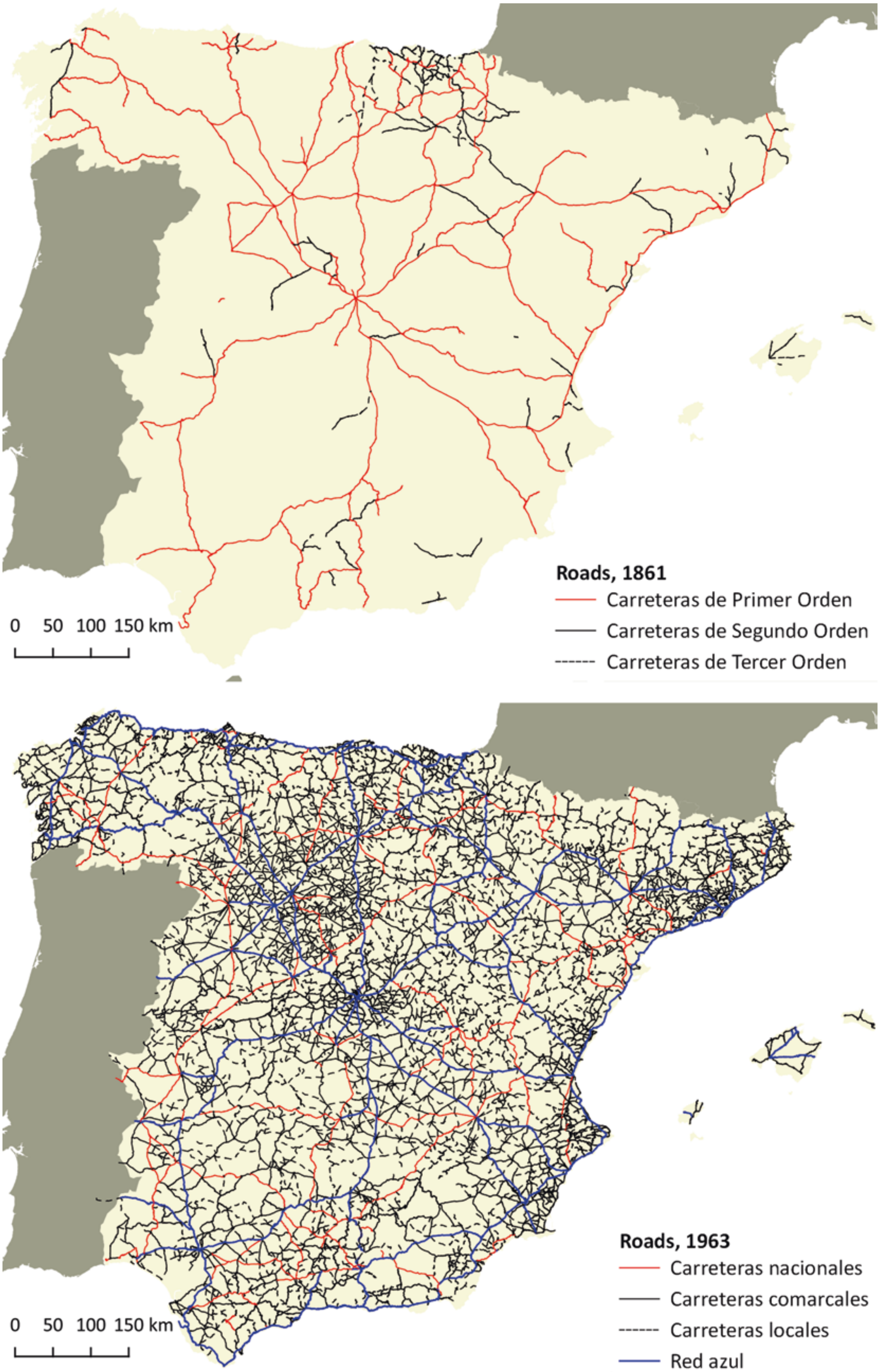

Fig. 3.4 Main, secondary and tertiary roads, the case of Spain: 1861 and 1963

Table 3.2 Number of vehicles in the European countries

PC	Private Cars
CV	Commercial vehicles
(thousands)	

	Austria		Belgium		Czechoslovakia		Denmark		Finland		France		Germany	
	PC	CV	PC	CV	PC	CV	PC	CV	PC	CV	PC	CV	PC	CV
1900		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9			
1910		0.0	0.0	0.0	0.0	0.0	1.0		0.0	0.0	53.7		31.7	4.2
1920	6.4	2.8	0.0	0.0	0.0	0.0	13.9	3.8	0.0	0.0	157.0	79.4		
1930	17.4	14.6	99.3	58.7	41.0	21.6	78.5	31.8	24.3	12.4	1,109.0	412.0	489.0	169.0
1940			110.0	58.8			7.0	23.3			1,800.0	500.0		
1950	48.5	43.9	274.0	145.0			118.0	61.4	26.8	34.4	2,150.0		591.7	468.8
1960	400.0	73.9	753.0	177.0	247.0	126.0	408.0	170.0	183.0	75.2	5,546.0	1,634.0	4,788.0	835.0
1970	1,197.0	121.0	2,060.0	376.0	826.0	218.0	1,077.0	252.0	712.0	116.0	12,900.0	2,745.0	15,101.0	2,198.0
1980	2,247.0	184.0	3,159.0	482.0	2,274.0	370.0	1,390.0	260.0	1,226.0	167.0	19,130.0	2,332.0	25,870.0	1,625.0
1990	2,991.0	253.0	3,864.0	591.0	3,242.0	462.0	1,590.0	301.0	1,940.0	294.0	23,550.0	3,567.0	35,502.0	1,826.0

	Greece		Hungary		Southern Ireland		Italy		Netherlands		Norway		Poland	
	PC	CV	PC	CV	PC	CV	PC	CV	PC	CV	PC	CV	PC	CV
1900														
1910											0.3			
1920			1.4	0.3			31.5	18.0	11.0		6.7	2.4		
1930	18.7	9.4	11.5	7.1	32.6		183.0	62.1	68.0	44.0	22.4	24.0	19.9	19.5
1940					50.2	11.7	270.0	87.5			48.8	38.7		
1950	9.3	22.4	13.1	8.2	85.1	26.6	342.0	229.0	139.0	82.0	60.1	56.3	40.1	46.4
1960	43.2	37.0	31.3	46.7	170.0	45.0	1,995.0	465.0	522.0	157.0	219.0	119.0	117.0	120.0
1970	227.0	118.0	240.0	89.0	389.0	51.2	10,181.0	904.0	2,600.0	302.0	748.0	152.0	479.0	260.0
1980	859.0	406.0	1,013.0	163.0	736.0	68.2	17,686.0	1,338.0	4,515.0	375.0	1,234.0	164.0	2,383.0	618.0
1990	1,736.0	793.0	1,945.0	289.0	796.0	150.0	27,416.0	2,495.0	5,509.0	582.0	1,612.0	331.0	5,261.0	1,045.0

	Portugal		Romania		Spain		Sweden		Switzerland		UK		Yugoslavia	
	PC	CV	PC	CV	PC	CV	PC	CV	PC	CV	PC	CV	PC	CV
1900														
1910									2.3	0.3	53.0	54.0		
1920							21.3		8.9	3.3	187.0	176.0		
1930			26.0	9.4			104.0	40.9	60.7	15.5	1,056.0	449.0	8.5	3.5
1940	39.1	11.0					34.6	46.7	65.9	18.1	1,423.0	525.0		
1950	60.5	28.8			89.0	83.0	252.0	94.5	147.0	38.5	2,258.0	1,032.0	6.4	17.1
1960	158.0	50.4	22.1		291.0	159.0	1,194.0	130.0	485.0	82.3	5,526.0	1,491.0	53.0	38.7
1970	551.0	147.0	45.1		2,378.0	741.0	2,289.0	159.0	1,239.0	255.0	11,515.0	1,694.0	721.0	122.0
1980	1,269.0	465.0			7,557.0	1,381.0	2,883.0	194.0	2,247.0	318.0	14,772.0	2,146.0	2,434.0	243.0
1990	2,552.0	813.0			11,996.0	2,334.0	3,601.0	325.0	2,994.0	482.0	19,742.0	2,844.0	3,511.0	

	TOTAL
1900	2.9
1910	200.5
1920	731.1
1930	4,874.3
1940	5,169.4
1950	9,228.9
1960	29,183.8
1970	78,495.3
1980	1,28,183.2
1990	1,81,127.0

Sources: Mitchel (1998)

concessions for motorways. As a result, transport policy is currently a central axis of the economic and regional policy of European states. Indeed, the EU has progressively acquired competences in the field of transport. It was initially involved in the liberalisation of services under the Treaty of Rome. Then, more recently, the EU has played a relevant role in coordinating transport policies in different member states.[5] There are numerous precedents for this vision of Europe as a single management area.

According to Mom (2005), transport infrastructure has been increasingly seen as a practical way to make European Integration a reality. The construction of integrated transport networks is not only an economic and social need but also a political project. In a famous speech addressed to the League of Nations' tenth assembly, on 5 September 1929, the French Minister for Foreign Affairs, Aristide Briand, explained his dream of a political federation of European states. Albert Thomas, director of the International Labour Organisation had previously formulated a plan for a European system which Briand's initiative detailed. His plan was a good example of seeking to mobilise the construction of large-scale infrastructure to achieve European integration, tackle the economic problems of the time and promote long-lasting peace on the continent. In this sense, Thomas was an "artisan of European union". With the support of Thomas and the ILO, road builders organised two European motorway congresses, in 1931 and 1932, and founded the Bureau International des Autoroutes (which was subsequently renamed the *Office International des Autoroutes*, or OIAR, in 1932) to promote pan-European motorway construction. At the same time, the subcommittee on road traffic of the League of Nations Communications and Transit Organisation took up the challenge of achieving greater European integration through road transport. This political context influenced the construction of the previously mentioned motorway project.

However, it was only after WWII that the ideas of these system builders were taken up. In July 1948, representatives of Belgium, Denmark, France, the United Kingdom, Italy, the Netherlands, Poland, Czechoslovakia, the United States, Sweden and Switzerland established an international highway network within the framework of the United Nations Economic Commission for Europe. By the autumn of 1950, 18 countries (including occupied Germany) were involved in planning a network.

The interest of the EU in promoting a road network covering the whole of Europe was the result of policies of regional rebalancing (Crescenzi et al. 2016). Policies following this line have since intensified over time and currently centre around the TEN-T programmes, which cover all transport systems, but particularly roads, motorways and railways (Gutiérrez et al. 2011). The EU has been particularly concerned with the primary-level roads that provide the main transport axes in Europe, while secondary and local roads fall within the competences of each member state.

The rapid growth in the use of the private car, associated with the availability of roads, has given rise to important debates about the accumulation of vehicles in specific spaces, and particularly in cities. The next section is dedicated to presenting and commenting on Mumford's (1895–1990) opinions about this phenomenon, as they have had a major impact. It is significant that the debates that he set in motion are still very valid. It is only relatively recently, however, that his views regarding the imperative need to change the current transport model have really come to the fore. The confirmation of the threat of climate change has been fundamental in getting society and the political establishment to take measures to limit the use of private motor vehicles. One of its derivatives has been the Smart City and plans to revitalise the provision of collective transport. However, the damage has already been done, and it is going to be very complicated to change the existing model. It is, however, important to bear in mind the current strategy of the automobile industry, which consists of developing the electric car. Its promotion is expected to receive a huge amount of public money, and this will further reinforce the massive use of motor vehicles. As we shall see in the next two sections, this also implies consolidating the model of the dispersed city and the perverse loop between the expansion of road transport and a city model that is not only dehumanising but which also destroys the environment.

There has been much criticism of the alliance between car manufacturers, petrol companies and political and other influential centres of power to place the car at the centre of the day-to-day life of citizens. It is true that these interests support and help perpetuate the feelings of personal status and independence that the private motor vehicle provides. However, its perverse result has been the massification of road transport which has, without exception, had an adverse impact on urban morphology (Chap. 12). It has also encouraged new personal habits that have produced an excessively intensive use of territory. The creation of enormous, low-density, urban suburbs would not have been possible without people being able to use the private car to go to work, go shopping and do other activities. Warnings of the potential counterproductive effects of this dynamic had already been given by Lewis Mumford (1895–1990), back in 1958, in a well-argued publication that we shall now examine in detail.

[5]Through its Regional Policy and ambitious programmes like the TEN-T.

3.3 The Premonitory Vision of Lewis Mumford Regarding the Negative Consequences of the Massive Use of the Private Motor Vehicle

Mumford was a sociologist and urbanist from the United States who was very critical of the way in which urban expansion was taking place in developed countries. In this section, we present his ideas and look at how the predominant commitment to a means of land transport—the motor car—has degraded the quality of life of the population. This is relevant to this chapter because roads and motorways do not only connect cities; they also enter them, totally modifying their ways of life. This theme is therefore also related to Chaps. 2 and 12. For a better understanding of this question, it is perhaps best to reproduce a selection of Mumford's emblematic writing on this subject, entitled: "The Highway and the City" (1958). Later, in Sect. 3.3, I shall refer to other recent authors who have denounced similar issues over 50 years later. This problem has only got worse because of the abusive application of supply-side approaches relating to the construction of new roads. This focus has been based on just one consideration: whenever the number of cars has been predicted to increase, the solution has been to provide more and more roads, seemingly ad infinitum. This implies a conceptual loop of "building more roads to meet a demand for mobility that is predicted to increase" which has dominated both public and private investment related to this means of transport. The considerations of Mumford and other authors are essential for interpreting the relevance of the historical perspective when looking for answers to some of the controversial questions posed by modern society. We must remember that the criteria employed in this book relate to a historical vision and that this is not just an introduction to the analysis of current themes, but something that teaches us that many of the problems encountered are not necessarily recent in origin. It demonstrates that there were discordant voices in the past, who suggested other alternatives. This could have led to a better society and one that we perhaps still have time to recover.

Mumford began his text by referring to road development policy in the United States, which he saw as the root of the problem. The most relevant thing to note here is that these policies, and their application, were subsequently followed and developed in Europe, in a cultural context that helped to coin a new term: "Americanisation" (Kipping and Tiratsoo 2018). In reality, the disproportional expansion of the use of the private car must be interpreted as the promotion of the cult of individualism. Only in this way is it possible to understand why we are prepared to accept the problems that this causes for our health, the natural environment and our rural and urban surroundings. Mumford's plea began as follows:

> When the American people, through their Congress, voted last year for a twenty-six-billion-dollar highway program, the most charitable thing to assume about this action is that they hadn't the faintest notion of what they were doing. Within the next fifteen years they will doubtless find out; but by that time, it will be too late to correct all the damage to our cities and our countryside, to say nothing of the efficient organization of industry and transportation, that this ill-conceived and absurdly unbalanced program will have wrought. (…).

To put these first affirmations into context, it is necessary to add that these policies were based on the North-American Law of Federal Aid to Highways, of 1944, and that they were consolidated through the formulation of the first models for traffic prediction, the transport study carried out by Thomas J. Fratar (1949) and the Highway Capacity Manual (National Research Council 1950). The latter was the first manual on motorways and was published in the following year.

Mumford continued:

> As long as motorcars were few in number, he who had one was a king: he could go where he pleased and halt where he pleased; and this machine itself appeared as a compensatory device for enlarging an ego which had been shrunken by our very success in mechanization. That sense of freedom and power remains a fact today only in low-density areas, in the open country; the popularity of this method of escape has ruined the promise it once held forth. In using the car to flee from the metropolis the motorist finds that he has merely transferred congestion to the highway; and when he reaches his destination, in a distant suburb, he finds that the countryside he sought has disappeared: beyond him, thanks to the motorway, lies only another suburb, just as dull as his own. (…)
>
> For most Americans, progress means accepting what is new because it is new, and discarding what is old because it is old. This may be good for a rapid turnover in business, but it is bad for continuity and stability in life. Progress, in an organic sense, should be cumulative, and though a certain amount of rubbish-clearing is always necessary, we lose part of the gain offered by a new invention if we automatically discard all the still valuable inventions that preceded it. In transportation, unfortunately, the old-fashioned linear notion of progress prevails. (…)
>
> What's transportation for? This is a question that highway engineers apparently never ask themselves (…) the essential purpose of transportation, which is to bring people or goods to places where they are needed, and to concentrate the greatest variety of goods and people within a limited area, in order to widen the possibility of choice without making it necessary to travel. A good transportation system minimizes unnecessary transportation; and in any event, it offers a change of speed and mode to fit a diversity of human purposes. (…)

As a result, the best solution would have been an efficient inter-modal system. However, as Mumford then explained, it was not planned along these lines. In fact, he affirmed that "The projectors of our national highway program plainly had little interest in transportation". This was a devastating criticism. It insinuated that, at that time, there were intellectual collaborators who were in favour of promoting motorways and who acted in favour of private interests rather than those of society as a whole.

> The fatal mistake we have been making is to sacrifice every other form of transportation to the private motorcar - and to offer, as the only long-distance alternative, the airplane. But the fact is that each type of transportation has its special use; and a good transportation policy must seek to improve each type and make the most of it. (…) There is no one ideal mode or speed: human purpose should govern the choice of the means of transportation. That is why we need a better transportation system, not just more highways. The projectors of our national highway program plainly had little interest in transportation. In their fanatical zeal to expand our highways, the very allocation of funds indicates that they are ready to liquidate all other forms of land and water transportation. (…)

By way of a conclusion, Mumford attacked the central theme of urban form and how the all-powerful and omnipresent motorcar had transformed people's ways of life. "We cannot have an efficient form for our transportation system until we can envisage a better permanent structure for our cities. And the first lesson we have to learn is that the city exists, not for the facile passage of motorcars, but for the care and culture of men".

Mumford's premonitory vision came true, as we shall explain in the next section. The essence of the supply-side approach was based on the belief that building more roads would not only favour the car-manufacturing industry and its lobbies but that it would also make transport policies popular. The next chapter presents some more recent transport policies and makes a number of reflections related to this problem.

3.4 Supply-Side Approaches, the Persistence of the Loop Between the Promotion of Motorways and the Car Invading the City

A jump in time shows us that this invasion by motorways is currently viewed in similar terms, 70 years after Mumford's warning. Manuel Herce and other authors have pointed out the contradiction that exists between the need to consolidate models for sustainable life and the approval of large public budgets destined for road transport infrastructure. The alternative should consist of drawing up previous, independent reports to evaluate the impact that each of these projects would have on the economy (cost-benefit studies), the natural environment and the way of life of the society in question. From this base, it would be possible to ponder the alternatives (opportunity cost studies) before taking final decisions about which items of infrastructure should be given priority. Some authors (Rus 2021) have made an enormous contribution to developing this line of work, which is so necessary and which is now being applied in modern-day projects. It would also be interesting to apply this approach to past works in order to obtain a broader critical vision, as we will comment later. Somewhat surprisingly, carrying out cost-benefit analysis before taking decisions is not mandatory. Furthermore, the obligation to present projects to the public does not resolve the problem. This is because citizens cannot be given responsibility for carrying out something as complex as making a reasoned critique of comparative opportunity costs relating to different options for how to invest public money. As Herce pointed out (2019), this system has facilitated the simplistic "approaches to demand that have guided urban transport research and planning over the last 50 years".

To interpret why demand-based approaches have been pre-eminent, it is necessary to look back to the origins of the urban planning movement, at the time of the International Conference on Modern Architecture (*Congres Internationaux d'Architecture Moderne*, CIAM), in 1928. Following this influential reference, it is possible to understand the reasons behind the planning guidelines that have governed urban planning and each of the other disciplines associated with it—including the planning of transport infrastructure—since that time. From then on, the dominant criteria that have governed interventions in the city have been:

1. Conceiving the city as a space divided into areas with land uses differentiated between residential, work, commercial and leisure activities. The problem deriving from this type of urban planning is that it creates a need for continuous movement between these different areas.
2. Giving exclusive priority to the road system and leaving the supporting role of building as a secondary consideration. The solution to this problem would be to limit transport axes to performing the basic function of providing cities with an organisational structure.
3. Giving the private motor vehicle pride of place as the instrument in which to entrust everything related to mobility. This has been done to the extreme that formal solutions have been designed that revolve around the space reserved for the car.

The predominant city model allows us to verify the important role that the development of road transport networks has played in their exaggerated expansion (Chap. 2) and in the highly dispersed location of different activities. The sum of these two factors has implied the massive use of private vehicles. The resulting problems have provoked a reaction: the application of demand-based methods —as opposed to supply-based methods—which are aimed at achieving a new model for the city and for urban transport. This new mindset implies understanding that the location of activities and their interrelationships depend on the form and organisation of infrastructure. Well-planned transport should therefore play a central role in limiting disorderly growth.

Overcoming the demand approach would make it possible to avoid the perversion implicit in using public investment for electoral purposes, such as planning public works in constituencies where the governing party has calculated that it is close to gaining a new representative in forthcoming elections. This is nothing new; similar practices also existed in the past. In the case of Spain, this has been the object of an interesting study conducted by Curto-Grau et al. in 2012 (see also Milligan and Smart 2005), who highlighted the interest in pork-barrel roads (1880–1914): roads that were not initially priorities but which were constructed to meet principally electoral interests.

The line of action required to combat such practices and to promote efficient and coherent transport networks has identified works that develop and apply an approach that consists of combining cost-benefit analysis (CBA) and multi-criteria analysis (MCA). This can be applied to any transport infrastructure. In the case of road infrastructure, this has been done with the aim of supporting an implementation of transport policy when prioritising projects (Gühnemann et al. 2012).

Despite studies carried out by independent institutions, investments are often decided by politicians who make decisions based on short-term electoral strategies. For this reason, public policies are often influenced by what is an essentially populist vision of the field of transport. This is based on a rather simplistic cause-effect relationship which equates more motorways with more activity, wealth and population. This argument has also been presented in relation to new railway stations for the modern high-speed train. However, the moment has now come to promote new opportunities in low-density areas; this is now much easier to do, thanks to access to the Internet across the whole territory. An appropriate level of inter-modality will also be a key element in these policies.

Having highlighted the problems and the conceptual antecedents of large infrastructure projects, in the next section, readers will be able to do some practical GIS exercises, using road data available in HGIS format.

3.5 Tutorial

Interest in the European road network is not recent, and there are numerous examples of this in existing cartography. In this chapter, we shall start by providing readers with the GIS corresponding to the work carried out by General Henri Dufour. He was the author of a series of European road maps which were produced during the first half of the nineteenth century. For these exercises, we have digitised a map corresponding to the year 1835, as this was produced just prior to the opening of a series of new railway lines.

This section will include H-GIS exercises at two levels: The European scale, based on a database of major roads in Europe (1835) and waterways in Western Europe, which were in service by 1850. We will also work at the national scale, using a new H-GIS for Spain that includes not only the main roads but also the secondary and tertiary level roads in service.

When we work with geographic information systems, road data tend to take the form of lines. As they are spatial data (they have coordinates), it is possible to do different types of analysis: calculate length, make analyses of networks and calculate optimal routes, calculate measures of centrality, etc. In this chapter, we will do the following:

1. We will create a map of roads (those operative in 1835) and of navigable waterways (in service in 1850) in Europe. We will add a base map with the relief, and we shall see how these communication routes took advantage of minimal slope.
2. Next, we will leave aside the historical perspective and focus on modern day motorways and dual carriageways. We will see which countries have constructed the densest networks of high-capacity highways.
3. Roads can also be represented using a quantitative variable. In the third chapter, we will use intensity as a measure of the importance of each road.
4. Roads can also explain the centrality of a municipality, based on the number of roadways that cross the municipal area and head towards the urban nucleus. We will work with the example of four Spanish cities, but it would be possible to apply this approach to any part of the world and also to any means of transport.

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The Expansion of Railways in Europe

4

Jordi Martí-Henneberg

Abstract

This chapter will focus on the morphology of the railway network in Europe in four specific years analysed in this study: 1850, 1900, 1950 and 2000. The map for 1850 shows a Europe in which it is not already possible to speak of a structured network, despite the considerable differences in density that exist amongst countries. Both England and Wales and Belgium were areas of greater density, but that was not the case with Germany, France or the North of Italy. Spain, Portugal, the Balkans and the Nordic countries had incipient railway networks but grew fast from then on.

The map for 1900 shows that the railway network had undergone a very significant transformation during the previous 50 years. The number of countries that now had a good level of equipment had increased even more, and those in the south of Europe had completed their networks. In the other peripheral areas, the situation varies enormously. The Nordic countries had considerably expanded their networks and mainly done so to a greater extent than in the more populated South of Europe. In the Balkans, there was a dual tendency: while the territory belonging to the Austro-Hungarian Empire exhibited a rapid rate of railway investment, progress was much slower in the Ottoman Empire.

Railroads data combined with already available GDP regional data will allow to explore the relationship between railway integration and regional development in Europe between 1870 and 1950 mainly, based on a regional dataset including 291 spatial units. Railway integration will be proxied by railway density, while per capita GDP will be used as an indicator of economic development.

The situation of the network in 2000 shows the dramatic decrease of railroads in use in some countries and the emergence of high-speed train lines.

Keywords

Railways network · Europe · H-GIS · Nineteenth to twentieth centuries

4.1 Introduction

Railways allowed steam engines to follow marked routes. This was a simple idea in theory, but one that was much more complicated to put into practice. Their development implied the collaboration of specialists from two very different fields of engineering: civil and industrial engineers. The technological, social and economic advances that drove the railway development were immense, and there is an extensive bibliography about them (Wolmar 2009). In this chapter, I shall focus on these aspects insofar as they have exerted a very marked spatial impact, for over two centuries, in the place where they were first developed: in Europe. The relationship between the railway and its area of influence has been studied on the basis of two parameters. Firstly, it has been looked at from the point of view of human geography, examining aspects prior to railway investment and which factors help understand the logic of the paths taken by the railway lines that were constructed, such as the location of population nuclei and productive activity. Secondly, it has been approached from the perspective of the transforming capacity of railway services. To be more precise, researchers have examined its role as a driving force behind economic and urban growth and also as a way of changing the mentality of societies (Figes 2019).

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In this first, introductory section, we will present the complexities of railway construction with the hope that this could serve to inspire new research. To help readers find more information on this subject, throughout the chapter, we shall cite some specific publications from the extensive bibliography that exists on this subject, part of which will be presented, in more detail, in Sect. 4.3.

One of the peculiarities of the railway is that it had to serve two very different areas of business on a large scale and often had to combine them using carriages coupled to the same locomotive: transporting freight and people. Initially, the railway was designed for the transport of freight, with great emphasis being put on facilitating mining activity, access to ports – whether maritime or on inland waterways – and the distribution of agricultural and manufactured products. The railway offered, as a novelty, regular transport with timetabled schedules, which transformed both business management and the postal service (Schwartz 2021 and Chap. 8 of this book). At the same time, amongst many others, it opened up new sectors, such as the production and distribution of milk to urban markets. In contrast, passenger transport was initially for a minority but grew quickly. Initially, the minority who could afford to purchase a ticket enjoyed Sunday excursions, as if they were forms of entertainment. This market was very small, however, as it was formed by an elite who already travelled using an alternative means of transport: the stagecoach. However, the use of the railway soon became more popular for tourist activities, for social and family meetings and also amongst business managers, who gradually incorporated face-to-face meetings into their business and management habits. Since then, the market share of the use of the railway for the transportation of people gradually increased, until it became its almost exclusive use with the arrival of new high-speed train (HST) services.

In this study of the railway in Europe, we shall examine the typologies of the six locational elements that any transport investment must take into consideration: the locations of urban nuclei, industry, mines, ports, international borders and capital towns, including capitals of provinces. Company strategies consisted of combining access to these elements in the most efficient way possible. The viability of their business would depend on taking two important variables into consideration. On the one hand, it was necessary to maximise the opportunity for business implicit in these connections. On the other hand, the rail system had to minimise the cost of constructing the network and maintaining the service. To do this, it was necessary to choose the most appropriate route, bearing in mind the cost of construction but also the time required to travel between the main nodes. It was also essential to design a network that could capture the greatest possible number of clients over the whole route. On top of this, it was necessary not only to satisfy the needs of the present but also to foresee future demand resulting from the development of human activities in a given country or even over a much broader area. The limitation of the railway was that it was static once it had been constructed, so the services offered could not be readapted in the same way as stagecoach or sea transport services. However, rail offered speed and punctuality in transport between strategic nuclei. For these reasons, major investment in railways was unleashed which called for professional planning, an unprecedented mobilisation of capital and modern business management. Along these lines, the creation of major rail companies had an equally large impact on the conception of the modern company (Chandler 1970), which was of great dimensions and was unprecedented in terms of its capital and number of workers. In short, railway companies had to bring together large-scale capitalists, managers, technicians and qualified labour.

Although the final decision on the route to be taken by the network corresponded to government plans and to the main owners of the companies, civil engineers were the ones who had to steer the strategic decisions that would condition the future of each company. In turn, governments and parliaments approved concessions and, in this way, gave their approval for the expropriation of land. For their part, engineers faced numerous challenges, which included the absence of previous topographic surveys that would have provided knowledge about the precise state of the terrain, which was essential for new endowments. The geographical institutes that produced the first series of national topographic maps (for the case of Spain: Nadal et al. 1998) were only created in Europe in the middle of the nineteenth century. For this reason, companies often had to assume the cost of new topographic surveys in order to decide the routes and to undertake the levelling of the land prior to the tracks being laid.

As has been mentioned, the circumstances in which the railway companies moved depended on the legislation of the country in which they were operating. The different states debated and passed their own railway legislation, in line with their circumstances and the prevailing balance of power. Each case was different, but they basically followed one of three models: the British, the French and the German (Mitchell 2000). Briefly stated, in the British model, the initiative lay with the companies, and the state simply legislated and approved concessions. In the French model, the state played a much bigger role, planning the main railway network but maintaining a rather more liberal policy with regard to the distribution of the concessions between different promoters. This, however, called for a programme of subsidies or guarantees of business for the companies, in other words, a large amount of spending from public coffers. Finally, the German model, which in fact originated in Belgium (De Block 2021), was initially based on liberal criteria. However, for strategic reasons that became clear after the Austro-

Prussian War of 1866, these railways were soon nationalised. In this case, the state took on the costs of investment and maintenance but also any potential profits, which, in the case of Germany, were important for some time. There is an interesting comparative analysis of the efficiency of different railway companies according to whether they were publicly or privately owned (Bogart 2010).

Although the general map of the European network may give the impression of being homogeneous, in each country, the railway system developed its own patterns (Martí-Henneberg 2013), which are explained in the next section. Even so, the majority of countries finally reached an agreement on a key issue: the track gauge. Despite the fact that in the initial period of railway expansion each section followed local plans and gauges varied, it did not take long before the logic of a wider network was accepted, with a view to encouraging international commerce (Puffert 2009). Fortunately, the 1.435 m gauge, which we shall call standard gauge, was adopted. Only in Spain was a different width applied, which, in turn, conditioned that of the Portuguese network. Something similar happened in Finland, where a wider gauge was used as it formed part of Russia until 1918 (1.52 m). These three countries, plus Ireland, still maintain their old gauge, but the new, high-speed, lines in Spain have been built using standard gauge.

Apart from this technical similarity relating to the chosen gauge, interpreting the characteristics of every stretch of track would call for a monographic study. It is not only the physical conditions of the setting that differ but those that enter the realms of human and economic geography: population patterns and the importance of neighbouring cities, the requirements of mining and industrial sites and opportunities for intermodal connections with other means of transport, such as maritime transport, via ports, amongst other considerations. On the other hand, in countries in which the state exercised central control and imposed a railway model, this could only be conditioned by local powers and their elected representatives.[1] This explains why the companies had to follow the logic of connecting all of the provincial capitals,[2] even though some of them were not very dynamic.[3] Alternatively, it was sometimes necessary to wait for the resolution of diplomatic agreements before projecting a cross-border connection, which normally also involved high-level involvement of the political and military hierarchy in two, or more, countries. In short, studies of stretches of railway or specific initiatives form part of an enormous bibliography and there are very rich sources that have made it possible to carry out this type of research work. However, in my opinion, the most relevant part of decision-making took place in offices without any official minutes being taken. To be precise, the choices about which properties to cross, or to leave free from the inconveniences of the railway, were undoubtedly taken according to the wishes of the people who were most influential in each area. Similarly, the strategy for building railway stations was key for the revaluing of certain plots of both urban (Bowie 2001) and rural land.[4]

The relevance of stations in the urban setting has been vital for promoting certain neighbourhoods but also for degrading or limiting others which had to face all of the inconveniences of the barrier effect of the railway. We shall dedicate a specific chapter to the subject of the constant dialogue between the city and the railway (Chap. 9). It is important to point out here, following the central theme about the network, that the actors that conditioned this were many and highly varied and acted in a specific way at each place and/or stretch of track. In countries in which local power was strong, their capacity to attract the railway station toward the centre of the city, or repel it, was often decisive. While the walls of the cities were maintained as elements of defence, military garrisons played a relevant role and often prevented stations from being constructed near to them, given that any such building could potentially be used by the enemy. Although for other reasons, it is relevant to point to the case of Cambridge, in the UK, where the local government and the university applied pressure to make sure that the railway station and therefore its rails were located at least 1.5 km from the historic colleges. In contrast, the station at Oxford is located just 300 m from Saint Peter's college, which was founded in the fourteenth century.

In the following sections, we shall, in this order, examine the evolution of the railway network in Europe; review the available literature on railway history and on GIS applied to the study of the railway; provide some guidance for collecting more information for those who would like to investigate or teach these subjects in the future; and, finally, look at case studies presented with the support of specific data.

[1] In the UK, this meant MPs in their respective constituencies and so on for each country.

[2] The administrative regions receive different names in different countries: county, *départément* (see Table 1 of Chap. 1 for all the counties in Europe, in Martí-Henneberg (ed), 2021, Introduction).

[3] This approach has been adopted to analyse the road construction in Spain (Curto-Grau et al. 2012).

[4] In the case of 3500 Ha of uninhabited terrain in Raimat, Spain, the engineer responsible for the railway work previously acquired the plot in order to later open a station in the middle of nowhere, but this enormously revalued his property (Nadal and Marti-Henneberg 2012).

4.2 The Expansion of the Railway in Europe

The analysis of the implantation of the railway in Europe calls for a dual perspective: relating to time and space. Here, we shall focus on the historical transformation of the railway network, while its points of access to the territory – the stations and stops – shall be examined in Chap. 10. Given that the perspective is global, and continental, we shall only study the standard gauge network. This will exclude the widespread development of the narrow-gauge railway network, because it was conceived to address the local needs of specific areas and therefore forms part of a different casuistry.

In the following comments about the European network, we shall move from making general observations to examining more specific cases, although the latter is also significant for getting and interpreting the general perspective. First of all, it is necessary to focus on a general vision, which is what is provided by the diagram and the map series presented in Figs. 4.1 and 4.2. A quick look at the map for 1930, which corresponds to the period of railway maturity, allows us to deduce that there were two large areas in terms of the density of the infrastructure endowment. Firstly, there was a central nucleus, formed by a continuous, transnational, territory that extended from England and the Netherlands to the North of Italy and included the majority of France, Germany and Austria. This extensive territory was served by a compact mesh of railway lines, which was only interrupted by mountains such as the Alps and the French Massif Central. The only area outside this one with a high provision of railway services corresponded to the urban-industrial area in the south of Scotland. In contrast, the countries, and regions, on the periphery of Europe had much lower densities of rail track. The centre-periphery model seems also to be clearly met in this case. In fact, comparatively low densities existed in several parts of the periphery: the Iberian Peninsula, Ireland, the north of England and the majority of Scotland, Denmark, the Nordic countries, Eastern Europe, the south of Italy and the Mediterranean islands.[5]

In order to interpret the maximum extent of the railway network in 1930[6] (Fig. 4.2), it is important to take a look back both backwards and forwards in time. Both exercises give us a very well-contrasted vision of the evolution of the railway in Europe. Firstly, observing the evolution of the network between 1840 and 1930 shows us that the countries which in 1930 had achieved a very-high-density network

[5]The complete map series for Europe at 10-year intervals at https://europa.udl.cat/projects/european-railways/

[6]The only lines that opened in Europe after 1930 were the result of specific cases or state policies.

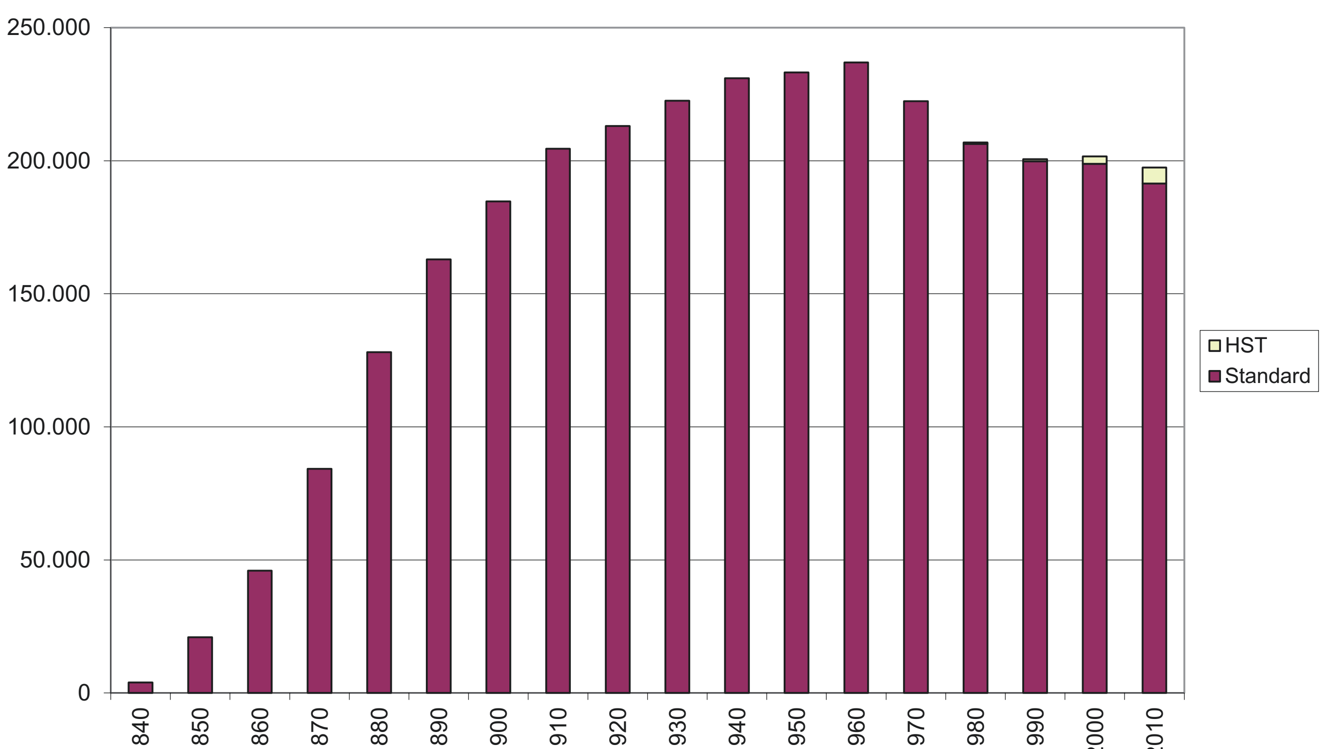


Fig. 4.1 Total length of railways in Europe, in km

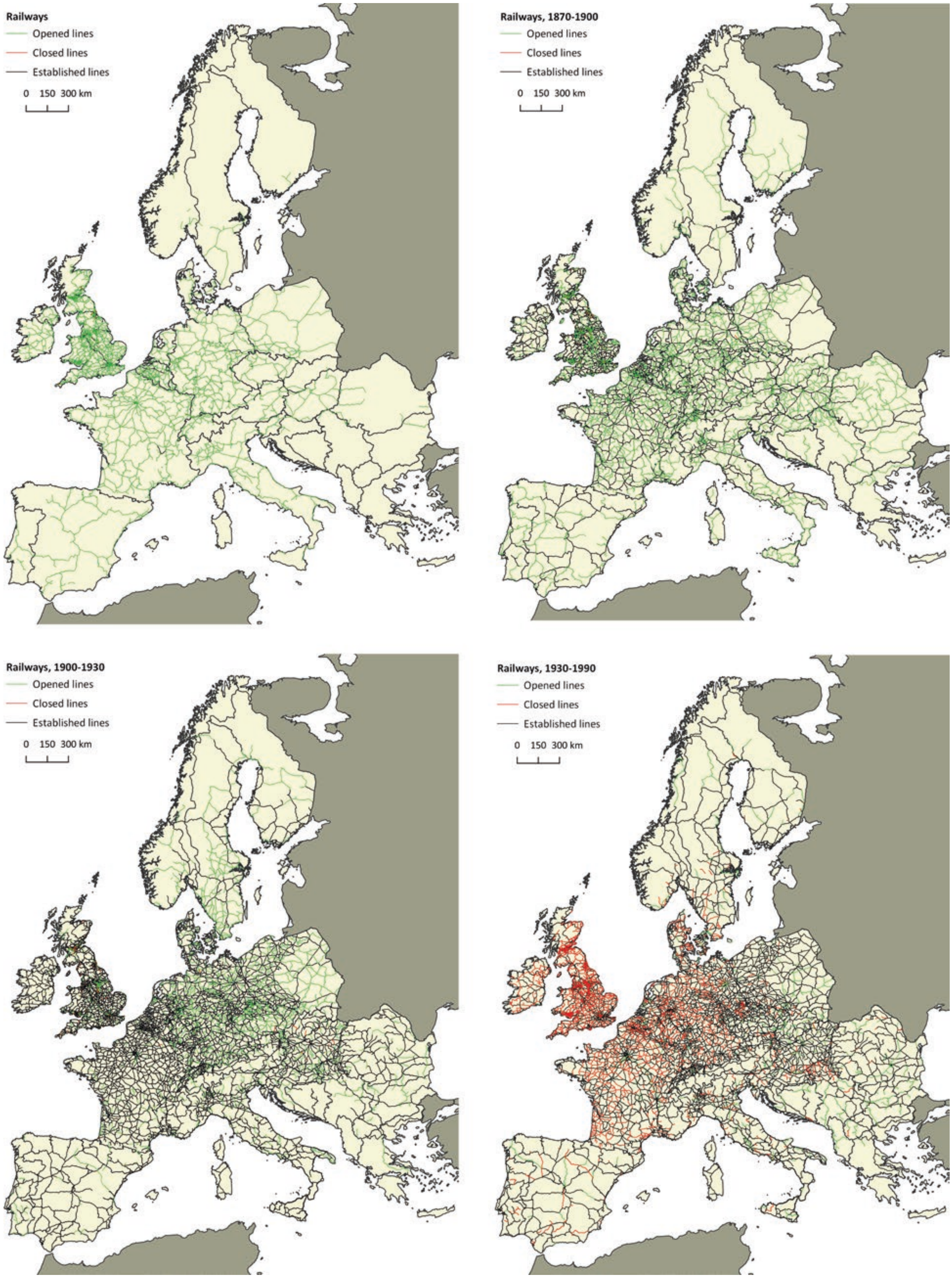


Fig. 4.2 The expansion of the Railways in Europe

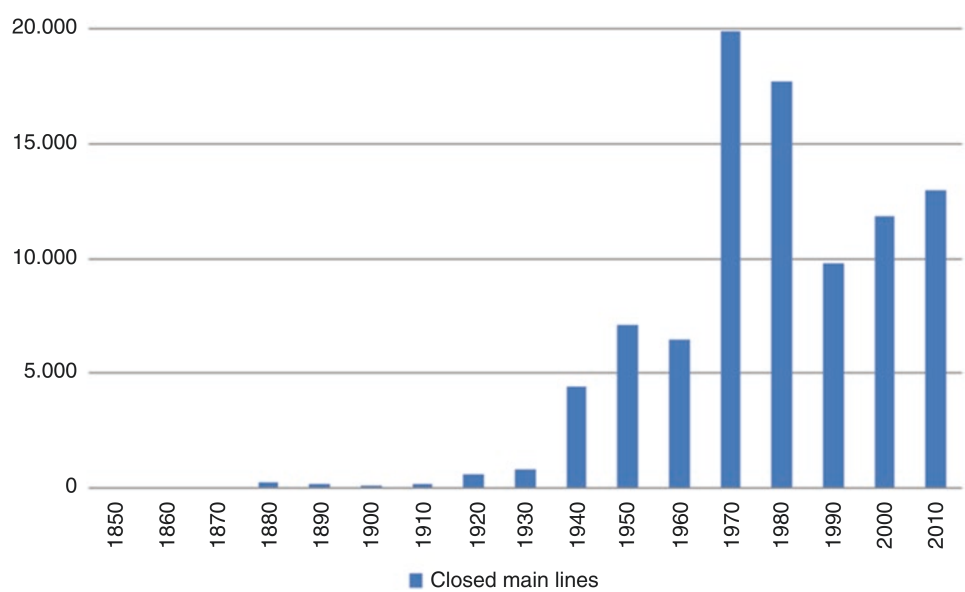
corresponded to those that had been the pioneers, and which between 1850 and 1870 had acted as a launchpad for the development of their network: mainly the UK, France, Belgium, the area of Germany (which was unified in 1871) and the north of Italy. Observing the maps in Fig. 4.2 in more detail, it becomes evident that in 1840, only the UK and Belgium had structured national networks, while in the area of Germany, the different states had interconnected, while the rest of the counties had only inaugurated scattered sections of track. The 1850s were years of rapid railway construction, with the previously mentioned countries notably increasing the size of their national networks; it was also extended in Ireland, the north of Italy and Austria-Hungary. Meanwhile, all the countries on the periphery were still only at the beginning of their railway construction process. In the 1860s, growth was generalised, as it was on the Iberian Peninsula and throughout Italy. From this point on, we shall use a map series in which line inaugurations and closures are highlighted in colour. Between 1870 and 1900, the network became even more consolidated in the central area, while on the periphery, this occurred at a slower pace. The Nordic countries only constructed basic lines, while those in the Balkans lagged behind in railway construction.

A comparison of the evolution in the next period, 1940–2000, shows that the countries that experienced the most changes were the same ones that had previously been highlighted as trendsetters, but in the opposite direction. In effect, the policy of line closures (Fig. 4.3) mainly affected the countries with the greatest density and where road and air transport grew enormously. These policies began to be applied during the period 1930–1960, mainly in the UK, Ireland and the rest of the central areas, which were already very densely developed. In the following period (1960–2000), the closure programmes became much more intense in these countries, as well as on the Iberian Peninsula, in Austria and the Nordic countries, and also in the west of Poland. This latter case will be treated in more detail.

In order to interpret these disparities between countries in terms of network density, it is also necessary to compare the length of the network (in kilometres) in service in relation to other relevant indicators, such as the density of population and economic activity. If this type of calculation is undertaken according to national population averages, the results are more comparable because, generally speaking, companies naturally tended to invest most where the business expectations were greatest; this, at the same time, re-enforced the greater economic dynamism of these areas (see Tables in Martí-Henneberg 2013). Having said this, it is also true that the countries with the lowest indexes of development used the railway as an instrument for territorial cohesion within their respective processes of state building (Marti-Henneberg 2013).

States were indeed central agents in the promotion of this new land transport infrastructure network, which leads us to two relevant considerations. Firstly, it is necessary to understand what happened in the states that saw their external borders drastically modified once the railway system had been fully developed. Chapter 1 presents all of the details regarding borders. Here, we point out that this situation mainly applied to Germany, Poland and much of the Balkans. As a result, we must ask ourselves what happened in countries that either lost or inherited a substantial part of a network that they had not themselves promoted. In some cases, this has given rise to countries whose railway networks exhibit

Fig. 4.3 The closing down process of Railways in Europe: 1850–2010



some astonishing contrasts. The case of Poland is the most convincing of others that we could cite.[7] For historic reasons, Poland has experienced historical circumstances that have radically modified its borders (Schulte 2021). If we look at the period of expansion previous to the peace treaties of 1919, the present territory of Poland belonged to Germany, Russia and Austria. This is reflected on Fig. 4.4, which shows marked differences in terms of the density of the network. The Russian territory is much less dense because this country had to create a network for an immense territory. This was the network that Poland inherited prior to its period of relative border stability: since the end of WWII. Poland has since had to decide what to do with such an imbalanced network. The answer can be found by comparing the map of 1910 with that of 2010, which shows two relevant ways of obtaining an integrated network. On one hand, the densities were rebalanced, which meant cancelling a large number of sections of track in the western half of the country – in other words, of the network constructed by Germany – and reinforcing the network in the east. On the other hand, ten new connections were established between the territory that had previously belonged to Russia and the rest of the country. It is therefore a case of great interest and one which shows the analytical potential of the historical perspective.

[7]The adaptation of railway networks located in areas that have passed from the control of one state to another can be studied in Ireland, Finland and the area which used to belong to the former Austro-Hungarian Empire and which was subsequently passed to the Balkan states. This is a line of research that has yet to be explored.

4.3 Some Selected Literature on Railway History

The history of the railway continues to arouse an enormous amount of interest, not only in the academic world but also amongst civil society. There are a great number of associations of friends of railways which are interested in the technology and also in the history of anything related to railways. Furthermore, the number of museums whose central theme is transport and, more specifically, railways is considerable. They tend to be very popular attractions and also often offer short journeys by steam engine, travelling in old-fashioned carriages. This is a good sign of the interest that there is in railways, which are considered a point of reference in our modern history. They also offer a mode of transport of increasing interest when it comes to finding ways to mitigate the effects of climate change.

The activity carried out at research centres and faculties on this subject is not alien to this general motivation. The reflection about the importance and impact of the railway has been widely developed in such disciplines as economic his-

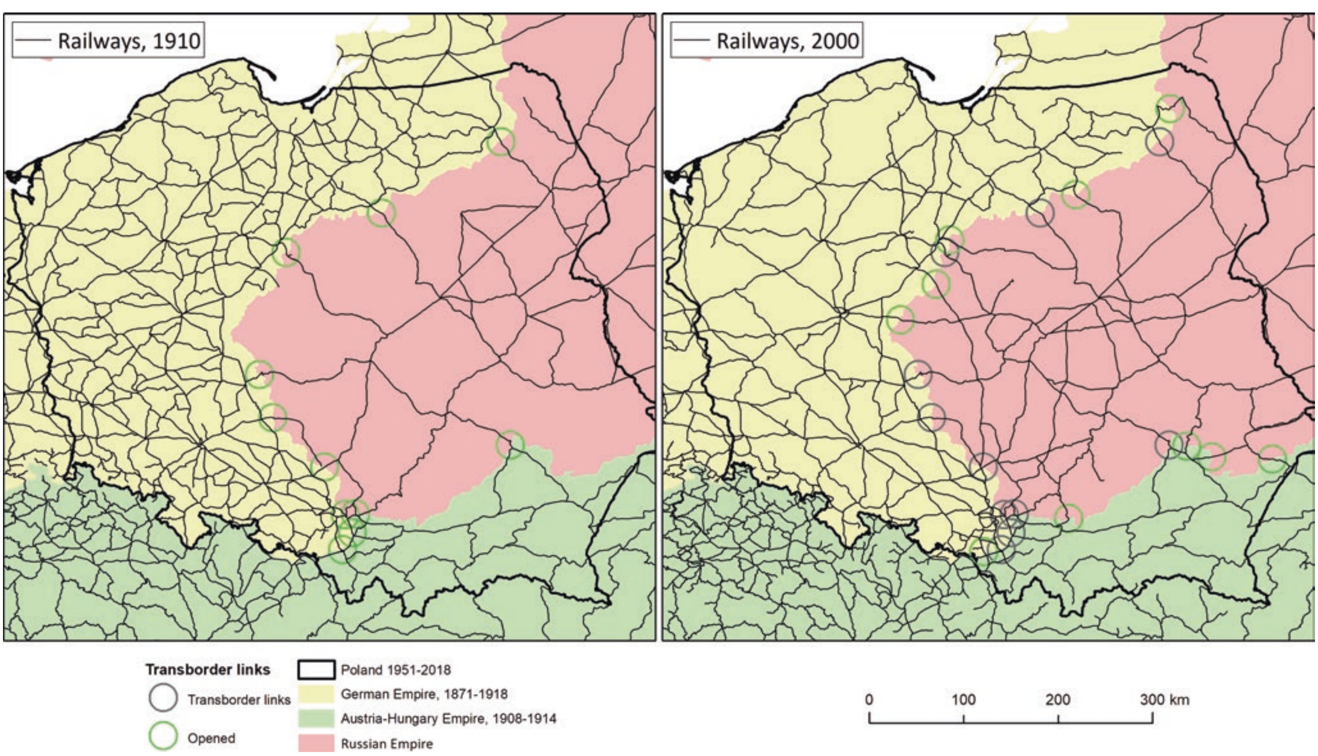


Fig. 4.4 The railways of Poland, in the middle of three Empires, 1910 and 2000

tory, geography, civil engineering, history and economics, amongst others. Approaches to the subject can be divided into two large groups, qualitative and quantitative studies, both undertaken at different scales, from the continental to the local. In this chapter, we shall mainly look at quantitative studies with a historical perspective. The theoretical base of this approach can be found in studies that adopt a path dependence perspective (Puffert 2002), in other words, works that seek to quantify the relevance that historical dynamics have had for understanding the present. This perspective is justified by the fact that the railway is not, in any way, a relic of the past, although it looked like this could have been the case when developed countries decided to promote road transport as opposed to rail. This largely occurred after WWII when it became apparent that maintaining and modernising the existing railway networks was going to require enormous quantities of public money. As already seen, the states which had the most extensive railway networks and underused sections then decided to undertake policies of large-scale line closures (Fig. 4.5 and Gibbons et al. 2018, for the UK). However, the railway has experienced a resurgence since the 1980s, for various reasons. This has mainly been due to the emergence of new high-speed technologies that have made HST very competitive with car and plane travel over intermediate-scale distances, of around 500 km. It has also, recently, been influenced by worries about the use of clean energy, which has led to the recovery of trams in cities and to an emphasis on collective transport. Historical works on railways therefore have a base in the worries of modern society.

Although the perspective on which we will mainly concentrate here involves H-GIS studies that implicitly lead towards a quantitative option, it is, without doubt, necessary to evaluate the qualitative works that have contributed to our knowledge of the past and corroborated the results obtained using H-GIS. One example of the relevant results that can be obtained from qualitative analysis is the study of the central role that railways have played in wars. This has been a demonstrable fact since the Crimean War (Bektas 2017), but it was also very evident in the two world wars (Mitchell 2000). In this case, the relation of the lines in service, their function in the movement of troops and intendency and the fights for their control have made it possible for us to build up some very accurate historical knowledge.

Quantitative studies have opened the way in parallel to the construction of databases suitable for use in GIS programmes. These databases basically consist of historical information about local population obtained from the censuses of each country (Schwartz et al. 2011; Silveira et al. 2011; Koopmans et al. 2012; Franch et al. 2013; Enflo et al. 2018). Other types of data have also been processed and studied according to the availability of information at the local level in each country: on occupations and environmental indicators, amongst other issues. In fact, all relevant information that can be geo-localised in a GIS can potentially be analysed in association with the database shapes of railways and stations. Efforts have also been made to compile data on the evolution of the railway network in Europe since 1830 in GIS format (Morillas-Torné 2012; Martí-Henneberg 2013). Similar work has also been done, in greater detail, for specific countries and periods (Kaim et al. 2020).

As well as census and network data, it has been possible to carry out studies of the impact of the railway on population and economic growth, both at the level of Europe (Koopmans et al. 2012; Zou et al. 2019; Alvarez-Palau et al. 2013, 2021) and also for specific countries and areas. Most of them used GIS in their analysis: in Spain (Herranz Loncan 2007; Franch-Auladell et al. 2013a, b, 2014; Esteban-Oliver 2020; Esteban-Oliver and Martí-Henneberg 2022); Sweden (Berger and Enflo 2017); Britain (Bogart et al. 2017a, b); France and Britain (Schwartz et al. 2011; Thévenin et al. 2013); Portugal (Silveira et al. 2013); SE of Europe (Mojica and Martí-Henneberg 2011); Northern countries (Enflo et al. 2018); Balkans (Stanev 2013; Stanev et al. 2017); and also the USA (Atack et al. 2010).

Studies have also been carried out using data for larger units, such as regions, although in this case, the precision of the results has tended to be lower. This has been the case of a recent study of how the railway endowment in each region influenced the growth in GDP over the period 1870–1910 (Alvarez-Palau et al. 2021). Some other studies have also been carried out and have analysed the role of the HST (Vickerman et al. 1999).

4.4 Tutorial

The railway is a transformative factor that has changed territories and also led to great transformations in their economies and distribution of population and also been responsible for social cultural changes, amongst others.

In these exercises, we will work with GIS to add the spatial data required to study these factors. In this case, we will use vector data in the form of lines that represent the railway network. We will carry out the following exercises:

1. We will calculate the density of railway lines in the different regions of Europe in the year 2000. The GIS will allow us to work with georeferenced data. In this way, we will be able to superimpose the railway data (lines) on the European regions (polygons) and to quantify how many kilometres of railway track were built in each region.
2. As we have historical railway data, we will be able to create a map showing the evolution of the European railway network between the years 1890 and 1930.

Fig. 4.5 The closing down process of Railways in Britain, 1950–1970

These exercises, which work with the whole of Europe, can be reproduced at different scales. It is necessary to bear in mind, however, that the layout of the railway lines that we offer here is not precise enough to work at large (supramunicipal and local) scales. In these cases, you will have to assume that the layout of the lines is approximate. There are, however, also other sources from which it is possible to extract railway lines. We will learn how to obtain railway lines for small territories from OpenStreetMap (OSM). This is an interesting source for two reasons:

- They are open data: the license is Open Data Commons Open Database License (ODbL).
- For territories with active communities, these are data that are constantly updated.

These types of sources open up great possibilities for working with GIS in the classroom.

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5 Ports and Freight Transport in Europe: A Historical Approach

Jordi Martí-Henneberg and Eduard J. Álvarez-Palau

Abstract

Transport infrastructures with greater visibility have always been terrestrial. Railways, roads and inland waterways are human-made infrastructures and are therefore more easily spotted within the built environment. Ports, however, are different. In remote times, their location was mainly based on natural characteristics, requiring a specific morphology of the coastline that would guarantee the shelter of ships from inclement weather. Inland ports, located on rivers of abundant horsepower such as the Thames, the Seine or the Guadalquivir, were ideal, but these cases were more the exception than the rule. The problem with coastal landing locations was that in many cases, they were not easily accessible by land, making it difficult to supply those goods to be shipped. With the technical revolution that constituted the invention of reinforced concrete, the former wood piers and beach wharfs near the big cities could be protected by dykes and breakwater piers. This allowed a gradual transition of the port geography; the less well-communicated natural ports began being abandoned and port cities started to gain momentum. The main consequence was a notable increase in the tons transported, due to a huge increase of ports accessibility from nearby cities. In this work, we propose to use spatial databases of historical ports and landing locations in Spain, France and England from the eighteenth century to the present day. These databases will be used to discuss the transition in coastal geography that involved the construction of the current largest ports.

Keywords
Ports · Maritime transport · International commerce · Europe

5.1 Introduction

In this chapter, the central theme is the study of maritime traffic passing through European ports, viewed from a historical approach. A global, comparative perspective requires identifying comparative data of different countries, with flows of ships and goods being the most relevant information. However, this type of data is often in quite short supply. As a result, few projects have addressed the subject of maritime transport from a historical and territorial perspective that transcends national borders. The most relevant is the World Seastems project, led by César Ducruet, that started with the records of Lloyd's of London, regarding daily ship movements. This study deals with the global maritime flows since the beginning of the eighteenth century, the creation of regional port networks and the process of urbanisation at port cities (Ducruet et al. 2012; 2018). To find a second project of a similar magnitude, it is necessary to go back to Cliwoc, led by Ricardo García-Herrera. In this case, the objective was to extract climatic information related to global maritime transport from shipping *logbooks* from 1750 to 1850. Although the orientation of this project was not focused on either ports or international commerce, the resulting database included references to over a thousand ports amongst its primary sources. Finally, it is also relevant to mention the Orbis project, whose main purpose was to model the intermodal transport of the Roman Empire, identifying the most relevant ports.[1]

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[1] For more information, see: World Seastems, Cliwoc and Orbis

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In terms of publications, interest in studying maritime transport has not ceased to grow. One of the most outstanding work is that of Pascali (2017), *The Wind of Change: Maritime Technology, Trade, and Economic Development*. Its author focused on the progressive introduction of the steamship on international trade routes to study its impact on trade and economic development. Other salient works, such as Speedier delivery: coastal shipping times and speeds during the Age of Sail (Bogart el al. 2021), *Safety at Sea during the Industrial Revolution* (Kelly et al. 2021) or *Ship speeds during the Industrial Revolution: East India Company ships, 1770–1828* (Solar and Hens 2016), stand out on account of their empirical approach to technological advances introduced on ships, and particularly the lining of hulls with metal cladding, and those that allowed significant improvements to be made to international sailing routes.

The contribution of this chapter is that of highlighting the interest of databases in GIS format for the study of ports and the economic activity generated at them, both in order to compare the relevant importance of ports within their regional context and for their diachronic analysis. This in no way, however, is meant to take away any value from monographic studies, which are of great interest and complement more general works. Each port facility has its peculiarities and unique features, and these can only be understood by interpreting them based on the history of each case. This chapter will insist on the need to evaluate the specificity of each port. Other transport infrastructures, such as railway stations and airports, are much more similar to each other. However, ports depend more on the physical conditions of their surroundings, on their urban morphology and on the historical circumstances and external factors that have influenced them over time.

5.2 The Role of Ports in Perspective

Ports are specific spaces that are highly unique. They are nodes which, since Antiquity, have made a decisive contribution to the movement of people and products between cities and their areas of influence. Similarly, a port is a place of transfer for goods of the most varied of kinds, and often unsuspected of origins, for their subsequent distribution on the mainland. The port therefore represents a place where the meeting of cultures, languages, ways of thinking and objects of the most varied types all come together. As a result, it is not only a place for the trading of raw materials or manufactured goods but also a forum for exchanging ideas, information and ways of organising society. The port is associated with a certain relaxation of the norms and laws of the country and also as being a place of opportunity and adventure. It is therefore no surprise that in port cities, the stable population lives alongside people who come and go, thereby creating a space of conflict but also of great creativity.

From the point of view of academic disciplines, different specialities have coincided in studying ports and their areas of influence. First of all, physical geography has focused on the position of the port on the continent: the characteristics of its site and situation, the advantages that it has when it is a natural port, and the topography of its marine substrate. Political sciences have also examined the relationship between the port and the institutions and economic powers, including questions such as its local and national fiscality and its capacity to attract public and private investment. Similarly, the port is a fundamental agent in the study of economics, as commercial activity is an indicator of the level of a country's economic development. In the field of transport, it is evident that ports are amongst the main nodes of intermodal transport for the shipping of merchandise at the global scale. Urbanism studies the role of port cities within a wider urban context and also examines how the layout of the port conditions its city's urban morphology (Pozueta 2006). Last but not least, anthropological studies include some very interesting case studies involving ports, which are relevant due to the variety of their inhabitants and the exchange of ideas that they facilitate.

For our study, what is really relevant is the contribution that each port makes to maritime transport, or rather, its most economic perspective. Given that each port is different but that, at the same time, it can only be interpreted within a wider context, a question to bear in mind concerns how it is possible to compare each port with the rest. There are different options in this regard, with it being possible to establish hierarchies based on the volume of commercial traffic and its maritime movement, on the demographic weight of its associated city or by calculating the more or less extensive impact on the territory of its logistical organisation. In any case, and as we shall see in the following sections, the indicators that are most commonly used to measure the size of a port are the number of ships that stop there and the tonnes of cargo transported.

It is true, however, that ports are always strongly rooted in local, regional and national logic. Even if the potential of their area of influence is large, their complementarities with the national and international economies are vital (Rozenblat 2004). This means that questions of scale are very important. To interpret the function of a specific port, it is necessary to simultaneously consider the local scale, or port city; the regional scale, through which it establishes connections with internal markets; the European scale, in our case (see Exercise 1 in the tutorial); and the transoceanic circuits. Their relevance is not the same, in hierarchical terms, and it can vary at each of the scales highlighted.

It is also necessary to take into account questions related to the typologies of ports, and not just their hierarchies, as defended by Jarvis and Lee (2017). These authors have taken different parameters which could serve as the base for a classification of the port typology. According to Jarvis and Lee, ports can be classified according to different criteria:

- Their main types of traffic: colonial products, undifferentiated traffic, passenger transport or specialisation in the importing or exporting of goods
- The model of port administration and whether it is a port administered by central government, a business concession, a provincial government or a private entity
- The nature of the trade: whether it is mainly importation or exportation or if it is a node for redistributing goods
- The tonnage of the ships that can use each port
- The commercial capital that is mobilised

However, a port is also a symbol in itself. The biggest ones are currently supranational entities in Europe, in much the same way that the main airports are. Due to their morphology, maritime walkways, the sights that they tend to offer and their role as witnesses of history, ports usually continue to be regarded as having a unique value. For this reason, they provide very opportune cases for applying the scope of path dependence. In other words, if there were no port today and it were possible to decide the location of those that were going to be built, without a doubt, in many cases, different locations would be chosen. However, historic tradition is a relevant factor for interpreting current reality. In the past, the conditioning factors were others, and they evolved in a different way. There have been many different explanatory factors: the commercial vocational and economic power of each country; facilities linked to river transport, which in many cases stimulated the creation of ports near the mouths of rivers (e.g. at Le Havre, on the River Seine, or Hamburg, on the River Weser); or changing global circumstances. In this last case, the greatest transformation of port geography in Europe occurred as a result of reaching America, which meant the beginning of the slow decline of the Mediterranean ports and those in the interior, in favour of those on the Atlantic coast. Similarly, the hierarchy of ports has been transformed for various reasons. On the one hand, this occurred in parallel with the modernisation of land transport, which finally put an end to short-distance cabotage transport, and meant that small ports largely lost their reason for existing. On the other, the concentration of advanced technology and the investment in the largest ports implied a concentration of commercial functions in them, rather than the previous much more dispersed spread. However, a port, as an open door to the sea, mainly owes its importance to the nature of its link with dry land. It is for this reason that the characteristics and the quality of access to ports are so relevant.

The gradual modernisation of ports and the growth of maritime traffic has been closely linked to technological advances in several very different fields. First of all, there were developments in techniques and knowledge applied to navigation: cartography, meteorology and forms of naval construction, which determined the efficiency of maritime transport and the size of ships. Similarly, there were advances in engineering applied to the construction of docks and machinery for loading and unloading goods. However, several external factors also influenced their capacity, such as the revolution in land transport, based on rail and road travel. The access of trains and lorries to ports made it possible to multiply the volume of freight traffic and also to extend the radius of action of each port within its nearby territory. The first massive-scale technological impact was the arrival of the steam engine, which was used in shipping and rail transport from the mid-nineteenth century onwards. Progress in navigation and economic growth generated a rapid increase in trade, which called for ports to adapt and to accommodate the resulting increased demand. The main outcome of this was that shipping by sea changed from being mainly focused on relatively short distances to taking on a transatlantic dimension. Globalisation gradually became consolidated until reaching the current situation, in which the relatively low cost of transporting goods by sea meant that over 80% of merchandise was carried by boat (Ducruet 2015. Pascali 2017). The use of containers and port cranes then supposed another technological and logistical advance, which facilitated intermodality and combining the transport of merchandise by ship, train and lorry from the point of origin to the destination.

5.3 Access and Port Hierarchy in Europe

Good access to the interior of a country and continent is a necessary precondition for port development. In preindustrial Europe, this depended on roads and tracks that were very irregular in quality. In the best of cases, canals and navigable rivers facilitated connections with the interior, with ports located at the mouths of river estuaries being the ones with the greatest potential for development. Examples of this were the ports of London, Rotterdam, Hamburg and Lisbon. However, the really important transformation came with the introduction of the railway network in Europe, from the middle of the nineteenth century onwards. The different countries stimulated its construction and guided its design in such a way that access to the main ports in each country became a priority. This objective was shared between states, whose ultimate objective was to equip themselves with an efficient transport system, and their railway companies sought to promote a profitable and lasting business.

Figure 5.1a combines data available for Europe: the railway network in 1870, whose limited development makes it possible to appreciate what the initial priorities were, and the average number of daily *port calls* at each port, to thereby identify the most relevant ones. The result was that the immense majority of them already had a railway station that favoured access to a long-distance line. Of the ports with

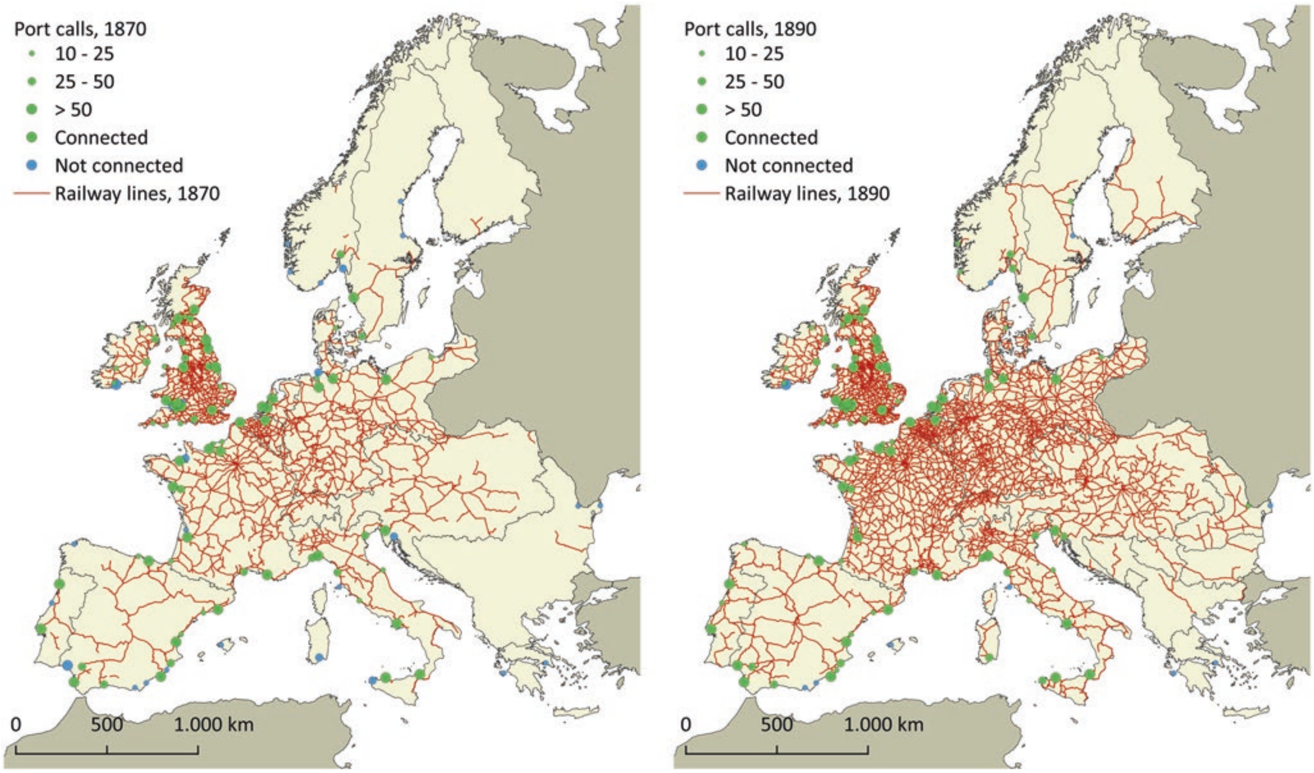

Fig. 5.1 Hierarchy of ports (port calls) and the railway network in 1870 (**a**) and 1890 (**b**). (Source: own research based on data from the HGISe and Ducruet et al. 2015, 2018)

over 50 *calls*, in Spain, Huelva was the only one that still did not have railway connection. As can be observed from Fig. 5.1b and Table 5.1, by 1890, the network had densified and the immense majority of ports now had a railway connection. There were few exceptions, and these can be identified in Fig. 5.1 and Table 5.1.[2] In 1890, the network was already very dense in the countries with the greatest dynamism. But in those with less density, it is possible to observe a railway map design which, to a large extent, can be explained by the will to provide access to ports. In Fig. 5.1b, it is possible to observe the case of Sweden, in which various stretches of track link interior trunk lines to ports. The same happened on the Iberian Peninsula, which had a system that was well connected to Madrid and to Lisbon and which developed radially in order to connect the different ports with the interior.

Combining GIS data relative to transport networks, ports and urban areas provides wide possibilities for analysis. In the final section of this chapter, which consists of the tutorials, attention will be given to showing the potential for the spatiotemporal analysis of this question.

[2]In Greece, the narrow gauge network – which covers most of the country – is not represented in this map.

5.4 Ports and International Trade: The Case of England and Wales

The importance of international maritime navigation in Europe has always been indisputable. The major European empires were built upon transport networks that connected territories on the same continent with those overseas. The Roman Empire, for example, established an important network of relations between the sea ports of the Mediterranean Sea, the Black Sea and the Atlantic Ocean which not only served for the shipping of goods but also for the movement of people and information. The Ottoman Empire followed a similar pattern, although in its case, it focused around more easterly ports located on the Adriatic, Aegean, Black, Red and Mediterranean seas. Years later, the pattern was repeated by the Spanish, British, French and Portuguese empires, amongst others, which connected European ports to others scattered across the geography of America, Africa, Asia and Oceania.

If we focus our attention on the case of Britain, the *Atlas of Industrializing Britain 1780–1914* (Langton and Morris 2002) offers us a detailed image of the importance of commercial relations and international maritime transport. From the end of the eighteenth century, the volume of merchandise transported began to grow notably. London specialised in

Table 5.1 Number of ports and railway connections to ports with an average of more than ten calls per day

Country	N° total ports	Connected 1870	Connected 1890	Not connected 1870	Not connected 1890
Austria-Hungary	2	1	2	1	0
Belgium	1	1	1	0	0
Bulgaria	0	–	0	–	0
Denmark	2	2	2	0	0
Finland	0	0	0	0	0
France	15	12	14	3	1
Germany	6	5	6	1	0
Greece	2	0	0	2	2
Italy	12	9	11	3	1
Netherlands	4	3	4	1	0
Norway	5	1	4	4	1
Ottoman Empire (part of)	2	0	–	2	–
Portugal	3	2	3	1	0
Romania	2	–	1	–	1
Spain	17	11	14	6	3
Sweden	3	1	2	2	1
UK	40	37	39	3	1

Source: Own research based on Ducruet et al. (2018)

colonial trade with the Pacific and via the monopoly conceded to the East India Company (Bogart 2017). Meanwhile, the ports of the south-east led its trade with Europe. Finally, the ports of the west focused on trade with Ireland and America. Imported products served to meet the demand for textiles, which were mainly used in the West Midlands and the north-west, near the newly opened shipping canals, and by the growing national population. They also served as an outlet for the coal production of the main mines (near Newcastle, Hull and Cardiff, etc.).

The nineteenth century began with a reduction in the total value of transported merchandise, which can mainly be explained by an important fall in the prices of raw materials. Furthermore, there was a change in commercial relations, with an increase in exports to Europe and America, and a reduction in trade with Asiatic countries. The most interesting period was that corresponding to the revolution in the development of port infrastructure. If we analyse the *harbour acts* that were passed by parliament to improve infrastructure, it is possible to note a clear increase in their number from the beginning of the nineteenth century. In decreasing order of *acts*, the ports with most interventions were London, Liverpool, Dover, Rye and Yarmouth, each with ten or more. There then began a period of concentration of commercial activity in a group of ports with modern infrastructure conditioned for the new requirements for loading and unloading from modern boats and from the new mode of land transport: the railway.[3] The result was a sustained increase in the volume of freight transported (Fig. 5.2).

[3]For more information about the evolution of the port system, see Alvarez-Palau and Dunn (2019).

At the end of the nineteenth century, when the great steamers were predominant amongst the international merchant fleet, imports from America focused on food products, construction materials and fuels. This included products ranging from Canadian fisheries to maize and cotton from the east coast of the USA, sugar and liqueurs from the Caribbean and coffee and minerals from South America. Dairy and livestock continued to be imported from the north of Europe, manufactured products from central Europe and fruit and wine from the south of Europe. Finally, trade with Asia was gradually reduced to spices and teas from India and rice and silk from China. With regard to exports, coal gradually gained increased relevance. Smaller-sized ships and the remainder of the sailing fleet were reorientated to cabotage and short-distance transport.

5.5 Ports and the Articulation of the Internal Market: The Case of Spain

We will use the case of Spain as an example for a joint analysis of the port system, its relationship with the design of the railway network and commercial traffic. This is a significant case given the geography of the peninsula and the low density of the railway network, in comparison with other European countries. It is important to highlight that it is only in these cases that essential priorities become clearly evident, precisely because the investment was limited. It is therefore possible to appreciate that establishing connections between the interior and the main ports was a priority from the beginning. In contrast, in countries with a much greater

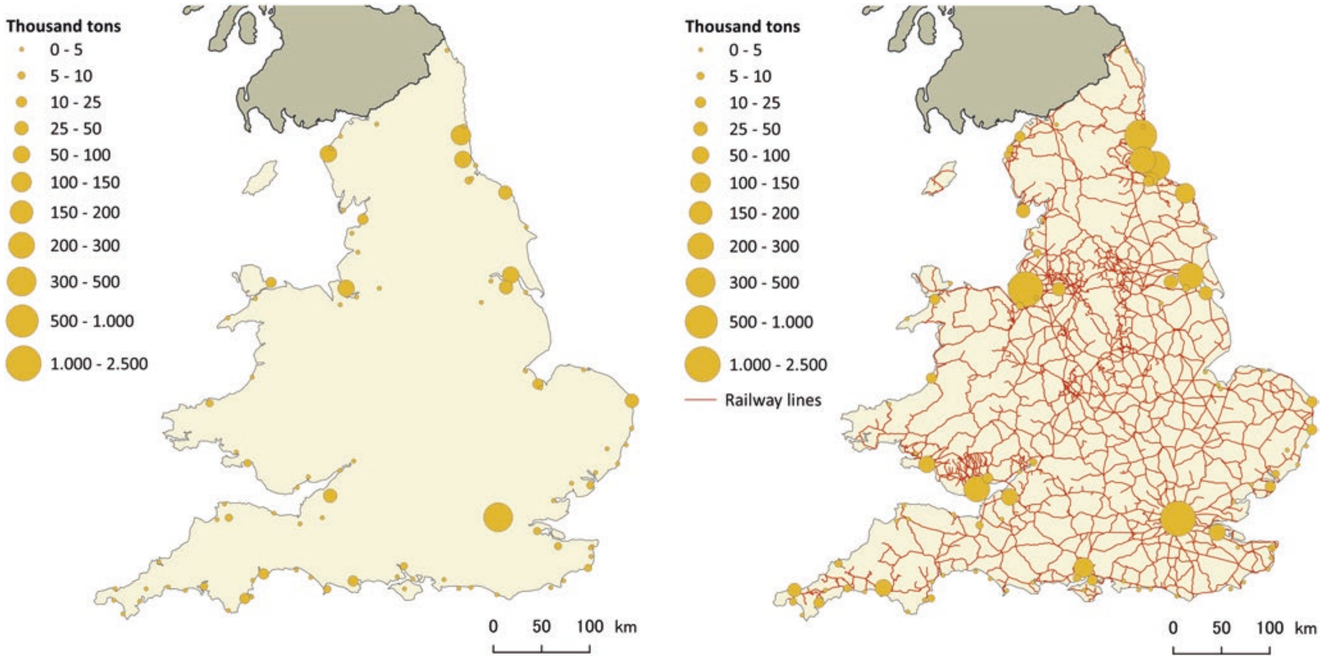

Fig. 5.2 Tonnes transported by the main ports, 1791 and 1901. (Source: authors article based on Langton and Morris (2002))

railway density (such as the UK, Belgium and France), practically all of the territory reached a very high concentration of track, revealing that infrastructure priorities were not so clear.

It is important to remember that, looking beyond its location on the peninsula and in the southwest of Europe, the geography of Spain has its own unique peculiarities. On top of a very long coast, it has very abrupt inland orography, with a pronounced roughness in the form of mountain systems and valleys. This has historically conditioned the spatial distribution of the population, with many important cities being along the coast and with population density being low in the interior. Only large cities like Madrid and Zaragoza have been capable of reversing this tendency and establishing themselves as important territorial nodes. It is evident that the concentration of population along the coast can be explained by the facility of access to international markets and to the ports. These have been able to mobilise great quantities of merchandise in both an economic and a relatively fast way. However, communications with the interior were another story. Beyond connections with the hinterlands of the port cites, at the beginning of the nineteenth century, Spain's internal market was still not very integrated. Although there was a growing road communications system, carriage transport was only competitive for carrying passengers and high-value, low-weight loads. It was not until the arrival of the railway that the situation underwent a drastic change.

The Spanish railway network was conceived according to the same infrastructure design schemes previously followed by its road network. A radial railway network was proposed that would connect Madrid to the different coastal regions in an independent way. The resulting connections, which in some cases were promoted by private companies and in others by consortiums involving the administration, connected Madrid to Catalonia, Valencia, Murcia, Andalucía, Lisbon, Santander, Bilbao and Donostia (San Sebastian). The importance of the contribution of the railway to overland transport cannot be questioned, but it also acted as a catalyst for the growth of maritime traffic which, from that moment onwards, could be channelled throughout the geography of Spain. Figure 5.3 shows how the railway network of 1870 was already connected to the majority of the main ports in Spain. The only important ports that were not connected were those of Vigo and La Palma; the former was not connected due to its peripheral position on the northwest of the peninsula and the latter due to its location on the Balearic archipelago. In 1890, however, the network connected all the Spanish ports, with only some of the ports in the south of Portugal remaining unconnected.

This infrastructure also helped increase imports and exports by sea. The transportation of minerals, such as coal from Asturias and non-ferrous metals from Huelva, increased in importance, as did that of agricultural produce (wine, fruit, etc.). These goods were transported by rail as far as the port, from where they were exported internationally. The development of the network therefore made it possible, not only to integrate the interior market but also to access international markets and to increase the value of surplus production. At the same time, and in the same way with Britain, the infrastructural requirements of the new ships, and also of the

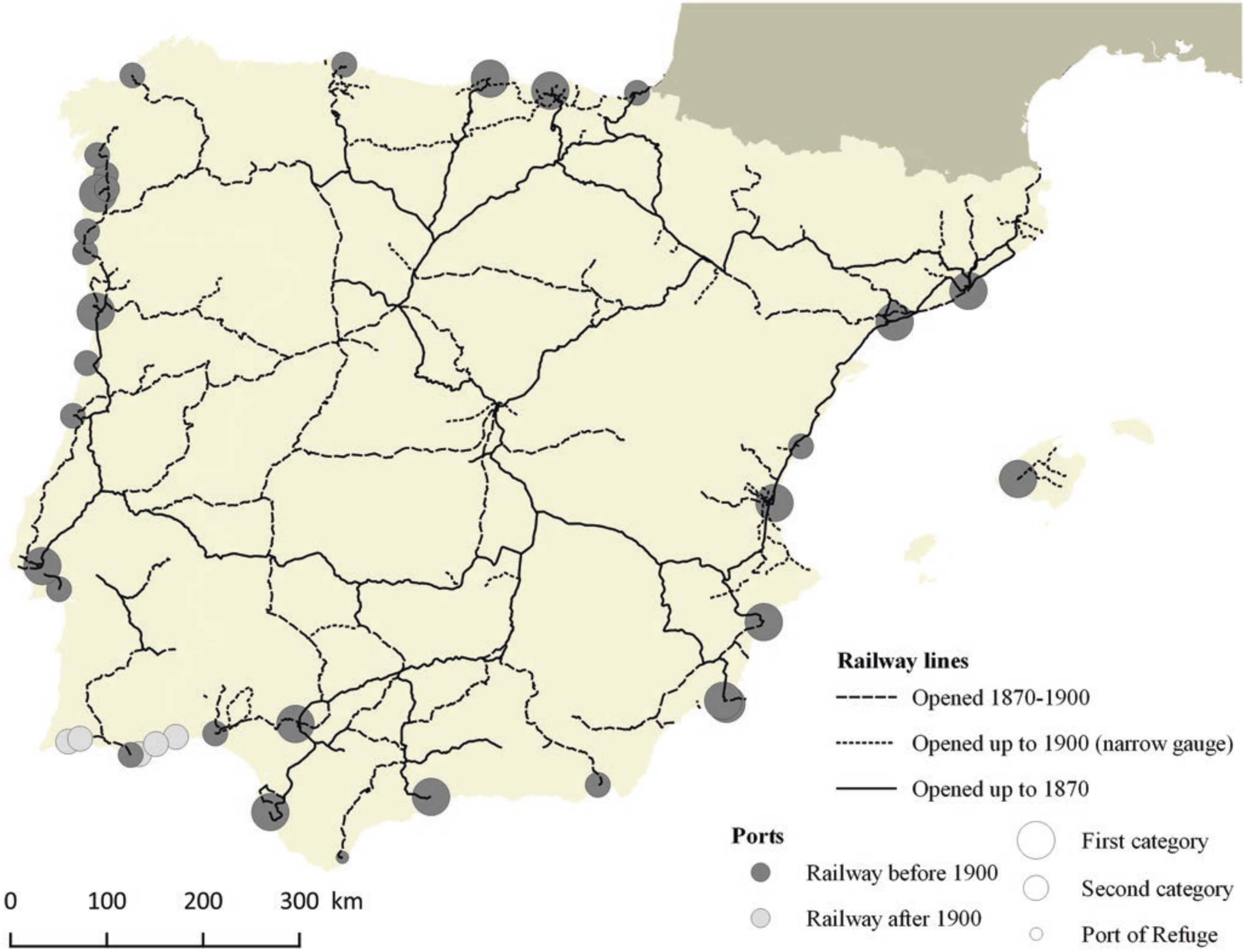

Fig. 5.3 The railway network and port hierarchy of the main Iberian ports in 1870 and 1900

railway network, made it necessary to construct a lot of new port infrastructure. Thus, international traffic gradually became concentrated at those ports that were best conditioned to receive, with the rest being left to depend on cabotage transport and on other, complementary, economic activities. Figure 5.4 highlights this phenomenon. Although a considerable number of ports were already connected by the railway network in 1870, the tonnes of goods transported were highly concentrated at a few specific ports (Cádiz, Gijón, Bilbao and Barcelona).

5.6 Conclusions and Relation with the Tutorial

This chapter provides an overview and comparison of the port system in Europe. Within a subject that already has an extensive bibliography, our contribution consists of opening the way for the study of specific ports, framed within their general context. This calls for a quantitative database which is what the GIS can provide. The two pieces of work contained in the tutorial will make it possible to put these two objectives into practice.

The first exercise will deal with systematising the study of the railway connection to each port. Calculating the distance between the station and the port facility provides information which is simplified but relevant for comparing the quality of the port/railway intermodality.

The second exercise assumes the challenge of associating data with each of the ports in order to carry out a comparative exercise. To be more specific, it involves georeferencing the records from a table and representing them based on their quantitative values. The content of the exercise shows the entries and departures of goods from the main ports in Spain in 1860. This could, however, be equally applied to ports in any country or region and, also, to any other type of data that refers to specific infrastructure within a spatial context.

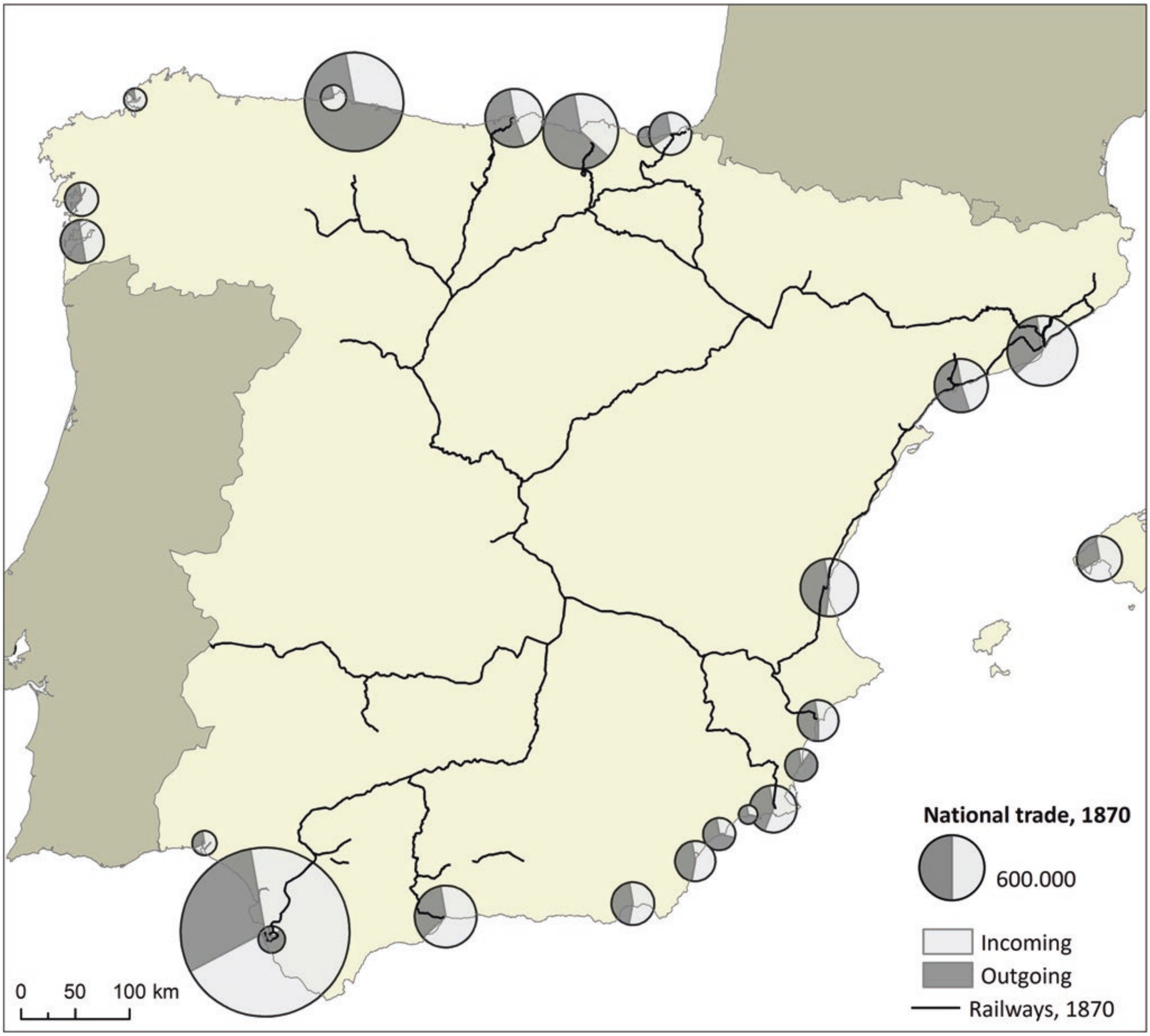

Fig. 5.4 The railway network and concentration of maritime transport at Spain's main ports in 1870

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6 Analysis of Inequalities Between Territories

Joana Maria Pujadas-Mora, Gabriel Brea-Martínez, and Jordi Martí-Henneberg

Abstract

This chapter is organised into a series of sections that will explain many conceptual and practical aspects of territorial imbalances. After an introductory Section 1, Section 2 will examine the importance of the territorial perspective in socio-economic analyses, both for interpreting their spatial characteristics and for guiding decision-making. Section 3 will explain the terms for debate on territorial imbalances. Section 4 will present various possibilities for spatiotemporal analyses relating to different geographical scales, ranging from that of Europe down to the municipal level. The units of analysis most commonly used are regional, but as we shall see, these can be subdivided into different levels. For these historical studies, we depend on the stability of borders and on the availability of data; these factors present a recurring problem throughout this book. At the EU level, a hierarchy of regions and local units was established in order to facilitate studies of the territorial reality; this served as a step prior to the management of financial aid. In fact, it was with this aim in mind that a hierarchical system was established for identifying different regional levels within the EU.

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Inequalities · GDP · Economy · Economic growth · GDP per capita

6.1 Introduction

The first thing that inequality suggests are differences between individuals in terms of their standards of living, social classes and opportunities. From the aggregation of the different situations that affect the people who live in a given territory, it is possible to obtain an average value, or indicator, of the standard of living in each area (which is normally an administrative region or municipality). This permits general geographical comparisons between territorial units and of their evolution over time. This spatio-temporal dimension of inequalities will be the main theme examined in this chapter. It should not, however, be forgotten that this type of study does not normally examine differences between the individuals in each territorial unit. As we shall see, calculations of inequalities between territories (imbalances, unequal distributions, etc.) may take population density, average (individual or family) income, per capita GDP and/or other indicators as their main points of reference.

With respect to the precision of this territorial analysis, the smaller the units studied, the more possible it is to observe the tremendous diversity (that is present in reality). This is because this approach makes it easier to identify differences between particular situations and to study their causes. As more data becomes available, it will therefore be possible to obtain more precise results from research conducted at the municipality level than using provinces as the basic unit of calculation. In this chapter, however, attention will mainly be given to the different scales at which comparative studies tend to be carried out: from the European scale to that of specific areas (such as streets) within municipalities.

As we have seen in Chap. 1, indicators have been available for the whole of Europe since the middle of the nineteenth century. As we know, the basic data normally refer to

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population, as these tend to be the most objective and the easiest to compare. The reason for this is that in our basic source, which were censuses, each person (and their characteristics) counted as 1, in any country or period; population indicators were therefore the ones most used. In contrast, the rest of the socio-economic themes took very different forms in the official censuses compiled in each European country from the nineteenth century onwards. Despite efforts to homogenise criteria, which have been made at international congresses on statistics since 1853, it was not until the creation of Eurostat (in 1953) that data on different themes (not only demography but also unemployment, living standards and economic activity) were unified in order to make them more readily comparable. The proliferation of databases and studies of territorial analysis is therefore relatively recent and predominantly based on information referring to the last few decades. These data have served as support for a growing interest in the territorial perspective[1] within studies of economic activity and society and have been developed into an important base of knowledge that has been used for guiding welfare-state policies in Europe since the 1950s (Flora et al. 1987). Such public support measures were initially aimed at those most in need, but it was not long before the territorial perspective was harnessed to help alleviate inequalities between different areas, as these are often factors that determine living environments and the expectations of individual citizens. Along these lines, it is necessary to remember that one of the founding principles of the EEC was that growth should be balanced. This was outlined in Article 2 of the Treaty of Rome (1957):

It shall be the aim of the Community, by establishing a Common Market and progressively approximating the economic policies of Member States, to promote throughout the Community a harmonious development of economic activities, a continuous and balanced expansion, an increased stability, an accelerated raising of the standard of living and closer relations between its Member States.

Based on these same principles, the subsequent Treaty of Lisbon (2008) specified the concept and policy of territorial cohesion. It is necessary to bear in mind that the Europe of the six founding countries only contained one area with problems of underdevelopment: the south of Italy. However, from 1973 onwards, the EEC expanded, and by 2016, the European Union (EU) had 28 member countries. Some of these are Portugal, Spain, Greece, East Germany, Poland, Bulgaria and Romania, including some very poor regions. In response to this problem, Article 3 of the Treaty of Lisbon specified that the EU "… shall promote economic, social and territorial cohesion, and solidarity among Member States". In fact, this cohesion policy had already, in practical terms, begun with the regional policy of the 1970s.[2] This gradually gained greater protagonism within the community budget, although its principles for action have not been free from controversy, as we shall see in Sect. 6.3.

This chapter is organised into a series of sections that will explain many conceptual and practical aspects of studies of territorial imbalances. The next section (Sect. 6.2) will examine the importance of the territorial perspective in socio-economic analyses, both for interpreting their spatial characteristics and for guiding decision-making. Section 6.3 will explain the terms for debate on territorial imbalances. Section 6.4 will present different possibilities for spatiotemporal analyses relating to different geographical scales, ranging from that of Europe down to the municipal level. The units of analysis most commonly used are regional, but as we shall see, these can be subdivided into different levels. For these historical studies, we depend on the stability of borders and on the availability of data; these factors present a recurring problem throughout this book. At the EU level, a hierarchy of regions and local units was established in order to facilitate studies of the territorial reality; this served as a step prior to the management of financial aid. In fact, it was with this aim in mind that a hierarchical system was established for identifying different regional levels within the EU (the NUTS, which were first mentioned in Sect. 1.3. of Chap. 1).

Today, the use of disaggregated databases even allows analysis at the neighbourhood level or that of individual blocks of flats, for themes of an environmental or social nature. This level will be examined in greater detail in the final section of this chapter (Sect. 6.5) and also in Exercise 5 of the tutorial, which looks at the level of streets within municipalities. Section 6.5 develops a case study at a very detailed scale as a way of showing the types of analysis which are feasible when very precise data about a given territory are available. There are a wide and varied range of problems and ways in which to analyse them. As a result, policies aimed at rebalancing territories are often the object of heated debate, as we shall see in the next two sections.

6.2 Conceptual Aspects and the Application of Policies That Favour Territorial Rebalancing

In this section, we present the relationship between the emergence of studies of territorial imbalances and the establishment of policies to achieve greater territorial cohesion. Given the interest aroused by the subject of imbalances in both aca-

[1] The greatest promoter of the geographic perspective amongst economists is Paul Krugman. His seminal work *Geography and Trade* (1992) defends the need to identify the geographic factors that make it possible to identify the development of economic activity.

[2] FEDER began in 1975 and was reinforced with Cohesion Funds from 1994 onwards.

demia and policy management, a great number of studies have been carried out to compare interregional differences. It is possible to present a few examples relating to income and opportunities for local inhabitants. There are, however, many other investigations that have served as the basis for the welfare state since the 1950s. Their development has been managed by states but also by regions and municipalities as the latter have gradually assumed more competences that were previously reserved for the state; this development has formed part of a general policy of bringing institutions closer to citizens. The EU, which has been given wide-ranging powers to intervene in economic, territorial and social affairs, has also made an important contribution to these policies.

However, despite these efforts, inequality still persists in Europe, both between people and territories. This calls for reflection upon its historical trajectory and on the convenience of, and limitations to, budgetary action in this area. In this section, we shall therefore make specific reference to various points of view regarding inequality and the different ways of approaching its study. It is best to begin by asking ourselves about the origins of the treatment of this issue.

It is certain that inequalities are inherent amongst individuals and societies, but it was during the Enlightenment that people first began to reflect upon their nature. One emblematic phrase that appears in the Declaration of the Rights of Man is that "Men are born and remain free and equal in rights"[3]; in fact, this has become an important cultural reference. Its origin lies in the *Discourse on the Origin and Basis of Inequality Among Men* (1755). According to its author, J.J. Rousseau, the original source of inequality is private property and the technological progress associated with it.

As we can see, inequalities between people have existed from the beginning of human society and continue to be one of its main concerns. Territorial inequalities, on the other hand, are – conceptually speaking – a much more recent concern. The territorial perspective allows us to conduct relevant analyses, such as identifying the average standard of living within territories, analysing their dynamism and, as a result, discovering the opportunities that are created in determined geographic contexts. This is relevant because proximity to nuclei where wealth is created generates opportunities for people. Rebalancing policies can then give priority to individuals or companies located in territories with limited expectations or that are marginal. Such policy is, however, generally expensive, and for this reason – as we shall see later – it is often the subject of heated debate.

When differences between territories are studied, it is necessary to take two different components into consideration when interpreting their performance. On the one hand, there are those that have a natural base and which condition the lives of their inhabitants. Economists have referred to these as "first nature" factors (Krugman 1993). They consist of readily available natural resources, the presence of ports and even a favourable orography to facilitate communications. The initial differences between territories are therefore determined by nature, although they may change with the discovery of mining resources or, for example, the application of new technologies to exploit these resources. The second component refers to "second nature" factors. This concept relates to the human capacity for organisation and to develop prosperity; this differs greatly between geographic areas and periods in history.

Combining the two groups of factors, the field of economic history has studied the differential development of different countries and regions. More specifically, econometric methods have been applied to measure the differential impact of these factors upon economic growth. One line of research which complements such quantitative studies considers the types of institutions present in each country or region as central instruments responsible for change. Although this variable is difficult to build into calculations, it has become a central argument in analyses of inequalities. Institutions, in the widest sense of the term, reflect how determined types of social organisation have, more or less, favoured development. By institutions, we understand – amongst other factors – the likes of financial agents, legislation that governs the legal guarantees given to investments and traders and the registration and efficient protection of patents. These types of factors can be used as the basis for explaining differences in the economic fortunes of different countries. This is a perspective that has been highlighted by Donaldson in *Why Nations Fail* (2012).

To this institutional perspective for interpreting differential growth, we believe that it is necessary to add an aspect that has received relatively little attention in historical studies currently available on this subject. This relates to the role played by the political representation of the territorial base, which is present in every democracy. If we situate the origins of today's constitutional nation states back in the nineteenth century, we note that the members of its legislative body have always been the representatives of the electors of determined territories. As a result of the maps of their electoral districts, the elected representatives chosen to enter parliaments have always given a disproportionately high level of representation to areas with little population, which normally coincide with peripheries. What is relevant about this is the fact that these representatives, and their parties, have always had to take into account not only the general interest but also that of the constituency that they were representing. As a result, from the very origins of the nation, territorial representation has obliged modern states to adopt a global per-

[3]The French National Constituent Assembly published the *Déclaration des droits de l'homme et du citoyen* (Declaration of the Rights of Man and the Citizen) on 26 August 1789.

spective in the management of their territories. That said, their development has not been balanced. For example, the industrial revolution implied the concentration of economic activity and the almost inevitable creation of certain unpopulated areas. On the other hand, technological transformations have accelerated change and often led to what were once prosperous territories becoming obsolete. It is the areas currently in decline that now need the greatest attention. Furthermore, in the long run, the sense that the inhabitants of a country have of belonging to a given district does not only depend on their standard of living but also on how they perceive the consideration and treatment that they receive from the most dynamic areas. Any possible neglect shown to the areas with the greatest deficits may lead to them being catalogued as being "left behind", which may have grave long-term consequences, as shown by the referendum on Brexit (Rodríguez-Pose and Dijkstra 2021).

The factor (aspect) that differentiates this chapter is the way in which it considers how contrasts between territories always crystallise from processes with slow dynamics; as a result, they can only be fully understood and interpreted through historical studies. One key period within this process is that of the consolidation of state building in each country,[4] as it marked the moment at which basic land transport infrastructure was created. One relevant example of this type was the public action associated with the establishment of the first railway networks. These policies show the types of intervention undertaken by the state within what was essentially a context of private investment in the majority of countries (also see Chap. xx on railways). These private companies naturally gave priority to establishing connections in the most dynamic areas, but states insisted that the plans followed integrated the whole of their respective territories, making sure that the railway system also reached the more peripheral areas by way of providing a system of incentives for investors. We must remember that these more marginal areas had political representation in parliament by that time and that their respective elected representatives would have lobbied to achieve the greatest possible investment endowments. This type of territorial intervention (Martí-Henneberg 2017) was first carried out on a large scale within a context that combined private initiatives, the regulatory function of the state and giving special attention to the most disadvantaged areas. It is relevant to highlight this point in the next few paragraphs.

The three maps presented in Fig. 6.1 (a, b and c) show a combination of regional indicators which were compared at the national scale for the years 1870, 1900, 1950 and 2000. The map series highlights differences between the two indicators that were used. The legend refers to the difference between the percentage of national growth potential concentrated in each region and the percentage of the national railway network located in the same region with respect to the country as a whole. The greater the negative difference (red and pink areas), the greater the coverage offered by the regional network with respect to that region's potential requirements (and the greater the re-balancing effort). In contrast, on the positive side, other regions were prejudiced in relative terms. These were normally areas that already enjoyed a high density of railway coverage but with a much greater level of urbanisation and greater potential for growth. In this last case, the re-balancing effort did not benefit the territory, although the provision of infrastructure may still have been sufficient.

As a result, without exception, the most highly urbanised areas suffered a relative deficit in infrastructure. This did not, however, necessarily constitute an argument in favour of a need for greater investment in infrastructure in these regions. More interestingly, the map series allows us to identify the amount of effort that was made by each state to favour its least dynamic areas and regions.

This general dynamic presents some interesting nuances when we compare different countries. Here, it is important to distinguish between those that already had established rail networks covering the majority of their territories by 1870 (the UK, France and Belgium), and the rest, whose national rail networks became consolidated at a later date. By 1910, the national networks of practically all of the countries studied (except the Nordic countries) had already reached their maximum level of development (Morillas-Torne 2012; Martí-Henneberg 2013). In comparative terms, it was these late developers that benefited most from railway investment. Furthermore, the extremely limited population densities in some of the most inland and northerly regions of the Nordic countries made it possible to highlight examples of internal colonisation in the nineteenth and early twentieth centuries. As a result, these are the areas with the lowest indicator values (see Fig. 6.1 and the series for 1870, 1910 and 1950).

As previously stated, the most relevant results can be observed in the areas with intermediate to low potential. Figure 6.1 shows that by 1870, the decision to invest in less developed areas had produced particularly relevant results on both the Iberian Peninsula and in the Austro-Hungarian Empire. By 1910, the majority of the rail network had already been established, and the panorama became even clearer. The number of regions with positive indicators was slightly

[4] It is necessary to define the concepts of "nation state" and "state building". According to the *Encyclopaedia Britannica*: a **nation-state** is a territorially bounded sovereign polity—i.e., a state—that is ruled in the name of a community of citizens who identify themselves as a nation. Whereas **state building** refers to the construction of a state apparatus (…). Given the tremendous differences between states in the course of history, "state building" may best be understood not in generic terms but rather as the result of political dynamics that bear the indelible imprint of their particular moment in history.

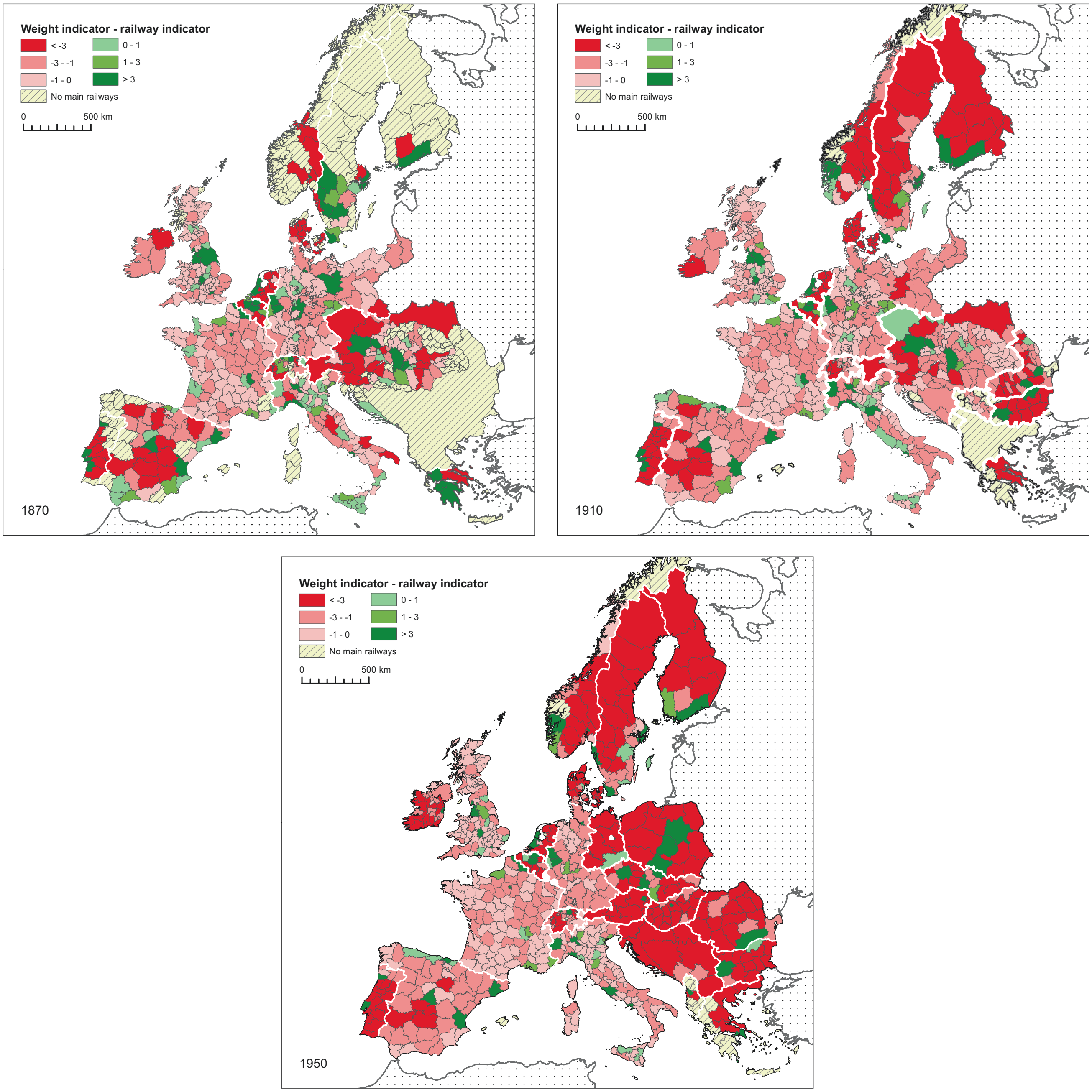


Fig. 6.1 (**a**, **b** and **c**) Series of three maps, 1870, 1910, 1950

smaller, whereas the territories that had received the greatest additional support (negative indicator) continued to be located in the most peripheral areas. In 1950, this tendency was further confirmed, but to an even greater degree, in the countries of Central Europe (Poland and the Balkans), where large territories received very high levels of investment in comparison to their real potential.

In the work summarised until so far, we have sought to use the differences between the expected investment, based on demographic and economic dynamics, and that which was really undertaken in different European regions in the 1870s, 1910s and 1950s. The conclusion reached was that the majority of countries carried out produced public-private investment that favoured their peripheral areas, albeit to different degrees. In some cases, such contributions were very significant, both in terms of the provision of resources and the fact that they were provided to areas that were distant from the most dynamic nuclei. Furthermore, the recipients were normally maritime regions, which had little possibility of providing services to traffic travelling between more developed areas.

The aspects described until now could be considered the forerunners of public policies designed to favour disadvantaged areas. However, setting them in motion at the levels that we are aware of was only possible once states had established expansive fiscal policies (Comín 1996). Only in this way was it possible, for example, to offer their citizens universal coverage in education and health care. There is, however, some controversy in the field of regional policy when it comes to evaluating the results of a policy that was based on dedicating a great amount of effort to favour the most disadvantaged areas. The fact is that there has been an effective redistribution of funds from the most dynamic areas and regions to the most backwards ones. This first took place at the level of the different countries and later within the framework of the EU. According to the perspective from which it is evaluated, the action taken could be considered either insufficient or exaggerated and uneconomic. The terms of this debate shall be explained in the following section.

6.3 The Debate About Territorial Rebalancing Policies

Given that resources are always limited, the core of this debate contains a dilemma: whether to favour and promote the most dynamic areas, in favour of the rapid development of each country or, on the other hand, whether to take investment away from the most prosperous areas and to redistribute it amongst the most marginal ones. This is basically a question of deciding between achieving greater efficiency in the use of public funds or giving priority to more backward areas and those in decline, which are normally in this situation as a result of having obsolete industry or because they are in peripheral rural areas. An essentially egalitarian discourse would give priority to the second option, but those who defend the argument of putting efficiency first claim that greater economic dynamism ultimately favours the whole of society, including the inhabitants of the more backward areas, who could emigrate to the more prosperous ones. In this section, we shall present the arguments for and against these two options.

It is clear that policies in favour of a general sharing of resources with the most disadvantaged regions of developed countries have been increasingly questioned since the 1990s. This has certainly been the case in the USA and Canada (Scott 1992). According to this point of view, the traditional way of providing aid to disadvantaged areas in Europe has failed (Fratesi and Rodríguez-Pose 2016). It is evident that the areas of Europe that have received most funds, and for the longest, both from their own states and from the EU, continue to lag behind. However, if such aid had not existed, the existing imbalances would probably be much greater, and this would probably have led to a dynamic of increasing contempt for poor areas, which would be difficult to justify in democratic countries. If we take per capita GDP as an indicator, the areas with the most problems (Fig. 6.2) are those in the centre and southwest of the Iberian Peninsula, the south of Italy, the majority of Greece, the north of England and East Germany. There has so far not been enough time to evaluate results for the countries that have most recently joined the EU, but everything suggests that these will remain amongst the areas most left behind.

Based on this reality, the neoliberal discourse advocates only investing where there is a guarantee of returns based on cost-benefit analyses (particularly on investments in transport) and on indirectly facilitating migration from depressed areas to those that offer a more attractive future. Such policies would, however, imply exacerbating existing regional divides, and their impact on disadvantaged areas would probably be irreversible. Despite this evidence, policies contrary to prioritising subsidies for areas in decline have been defended in numerous studies in the field of urban economics (Duranton and Puga 2004; Combes et al. 2012) and also by the World Bank. In fact, this institution affirms that "… the main aim of policies should be to move people to places where there are opportunities, not opportunities to declining areas" (World Bank 2009).

Against these arguments, it is interesting to note that the increased awareness of those affected has had a geographical component. This is shown by the fact that it has been people who live in depressed areas (rather than the poor living in rich areas) who have reacted most clearly. What is more, their protests have been manifested in support for demagogic political options, such as Brexit, which obtained a very wide level of approval in the north of England (Rodríguez-Pose and Dijkstra 2021).

If we look at urban areas, we note that numerous major cities in developed countries have become examples of prosperity that also promote integration and human development. This is not, however, evident in all cases; there is not, therefore, evidence of a cause-effect relationship between the size of the city and balanced development. What has been shown, however, is that numerous intermediate cities have managed to promote high levels of progress and quality of life (Frick and Rodríguez-Pose 2018). These cities have also disseminated their dynamism within their respective regions. This points to the possibility of designing a different option from that of simply supporting the largest and already most dynamic nuclei. Thanks to the development of their intermediate cities and to public support, the majority of countries in Europe have seen a reduction in their territorial disparities over the last 30 years.

In short, inequalities are inherent to the nature and development of human activity within a given territory. However, public action can help modify their dynamics. A recent study (Achten and Lessmann 2020) has shown that the heterogene-

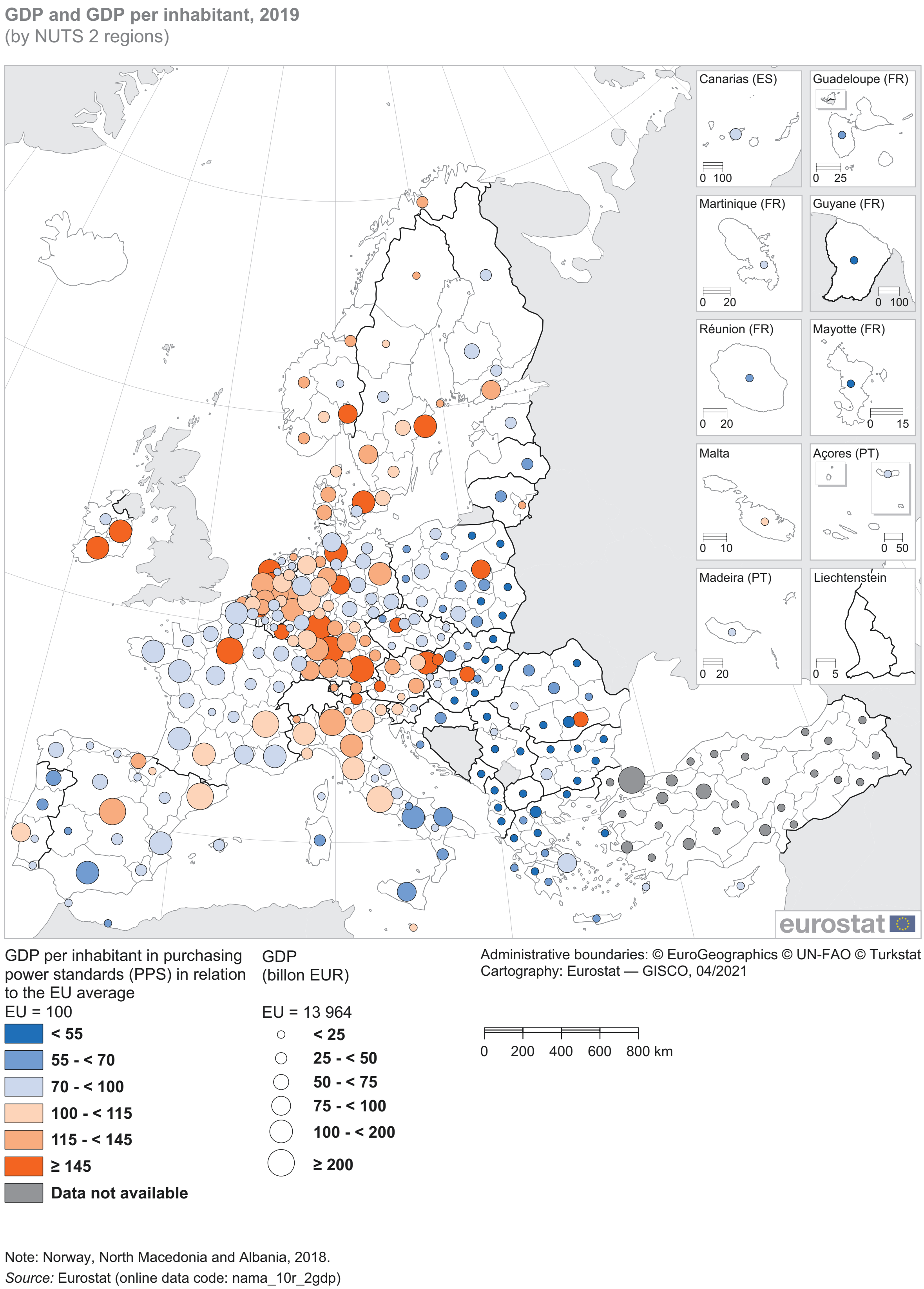


Fig. 6.2 Total GDP and GDP per inhabitant by regions, Europe 2019. (Source: GISCO)

ity of the physical geography of a country is an important determinant of economic activity. These authors used the density of road transport infrastructure to show how such investment can mitigate the basic disequilibria in the world. Amongst specialists – and particularly those in the academic world – arguments in favour of territorial rebalancing tend to predominate. This may, however, be due to the power of the majority opinion in the circles in which each of us tend to move. There is well-known reticence to neoliberal ideas in the university world, particularly in Europe, and especially in departments of geography. This majority has been converted into almost total unanimity in the uncritical documents produced by the European Commission to publicise its own activities and results.

In the next section, we shall highlight a few examples of territorial analyses, this time putting emphasis on the different scales of analysis. Each of them makes it possible to detect different problems, although we have failed to find any references to this question in the literature consulted. The theme of Sect. 6.4 will be developed in greater detail in the tutorial.

6.4 The Analysis of Inequalities at the Regional Scale

Each scale of analysis permits a different and yet complementary approximation; their combination therefore provides a better guide for policies aimed at mitigating inequalities. On the one hand, we have the small scale, which is when we cover a whole country or continent. Although detail is lost in this case, we achieve a wide vision of the whole. The opposite situation is the large scale, such as that of the municipalities within a region, but in this case, we lose the context that the total set of regions give to the state or the continent. The ideal situation is therefore to have combined, multi-scale studies, based on the same theme. This would be the ideal situation in this chapter, in order to offer a historical perspective, but – unfortunately - the indicators available are not the same for each scale and period. In this section, we shall present our study levels using historical regional data. The first covers the whole of Europe, while the second refers to a group of countries.

Finally, in Sect. 6.5 of this chapter, we will examine the subject of inequalities within a small and very specific territory. However, before doing this, we shall first provide a schematic presentation of two levels of analysis based on historical data.

When we consider the whole of Europe, the amount of available historical data is rather scarce. There are then further problems concerning how best to represent and analyse these data, particularly given the fact that the territorial units in question (regions), have undergone numerous modifications (see Chap. 1). Despite this, we can cite several relevant reference works.

In the case of population density, it has been demonstrated that inequalities at Europe's NUTS 3 regional level have been exacerbated over time. In fact, a long-standing and well-established dichotomous structure has tended to become increasingly consolidated over time. This has occurred despite enormous changes in the factors that have determined the location of population and economic activities since 1870. All of the indicators relating to population density examined in this work point to an increase in territorial imbalance over time. This is confirmed by a range of data that includes standard deviations, correlations and the map series included in a previous article (Figs. 6.3 and 6.4 in Martí-Henneberg 2005).

It is also evident that the process of rural-urban migration has been the root cause of the exacerbation of Europe's population disequilibria (Fig. 6.3). This has been the direct consequence of the change from a form of highly labour-intensive agriculture to one based on the widespread use of capital. To date, these phenomena have only really been widely studied at the local and national levels, but this article offers a European context within which it is also necessary to examine these phenomena.

From Fig. 6.3, it is possible to observe that the logic for establishing regional boundaries has not remained the same throughout the period studied. This is particularly easy to note along the eastern border of Europe. In order to maintain stable units, and ones that are therefore comparable over long periods of time, another study was carried out (Gregory et al. 2010). This involved using data on regional population density and interpolating[5] the areas that had experienced boundary changes. The results can be appreciated in Fig. 6.4, which confirms the long-term tendency for the population to concentrate in Europe (see also tutorial).

Finally, in a study of regional GDP, the authors (Diez-Minguela, Alvarez-Palau, Martí-Henneberg, 2021) examined the relationship between railways and the growth of regional per-capita GDP in Western Europe from 1870 to 1910. This approach benefited from a novel database based on 291 spatial units (including 287 regions and 4 countries). The conclusion from the study was that the regions that had the densest railway networks in 1870 were not "caught up" by the rest (Fig. 6.5). Although investment in railways and the process of national market integration that followed was of paramount importance for both the industrial core and the more peripheral regions, the second wave of railway construction seems to have only benefited certain peripheral regions, thereby exacerbating existing regional disparities in Spain, Italy and Portugal.

[5] The approach is explained in full detail in the article.

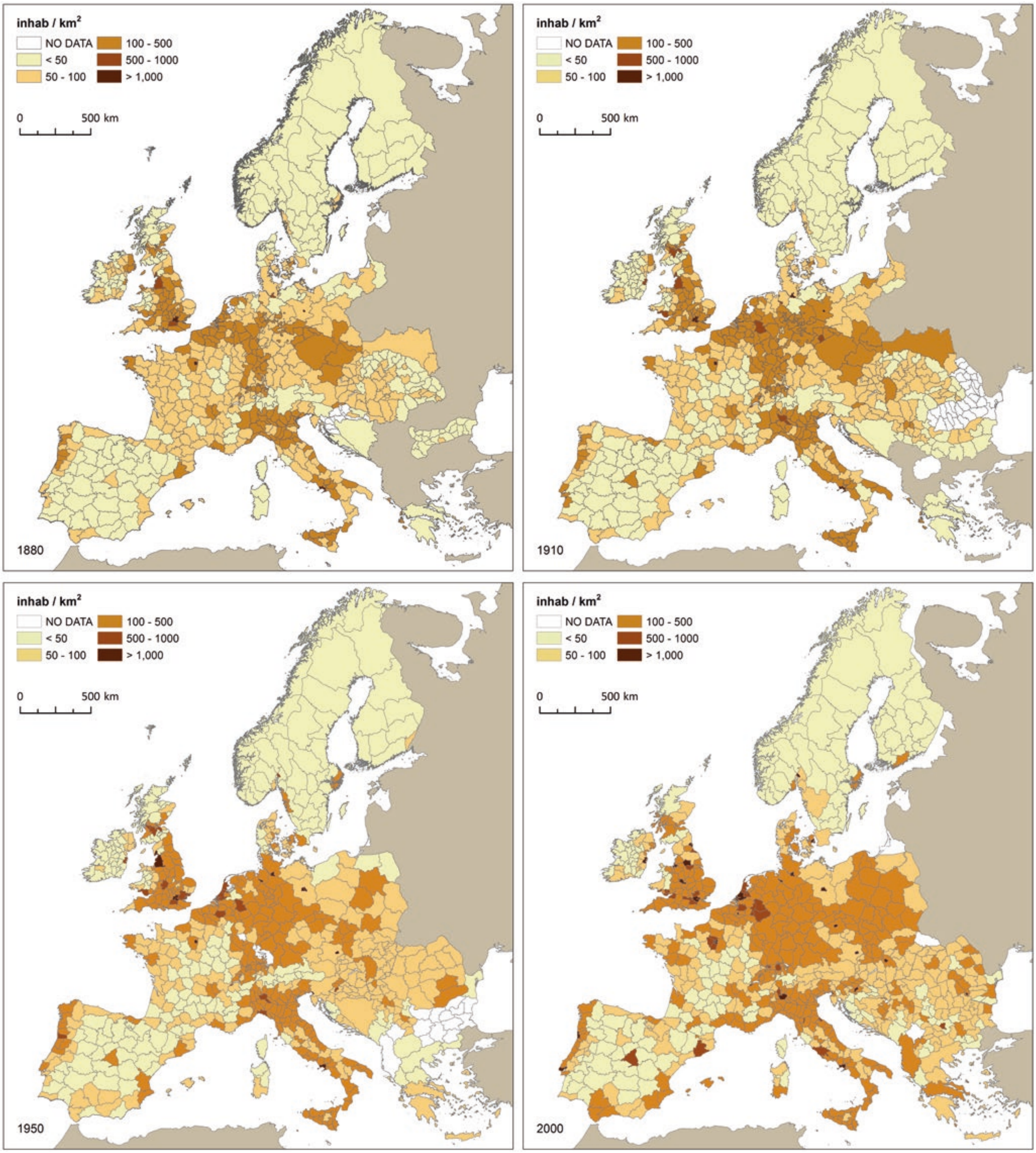


Fig. 6.3 Population density in Europe: 1880, 1910, 1950 and 2000

The most extensive study of the differences between regions carried out in Europe, from both the temporal and geographic perspectives, analysed the period 1860–2010 and focused on France, Italy and the Iberian Peninsula (Díez-Minguela et al. 2019). Based on data relating to per capita GDP at the regional level, this article identified cycles of economic expansion and analysed their relationship with a possible concentration of activity. Since Williamson (1965), it has been known that such relationships are not linear and that over the period of modern economic development, the growth of regional inequality has exhibited an inverted U-shaped pattern. In the first period, inequalities diminished,

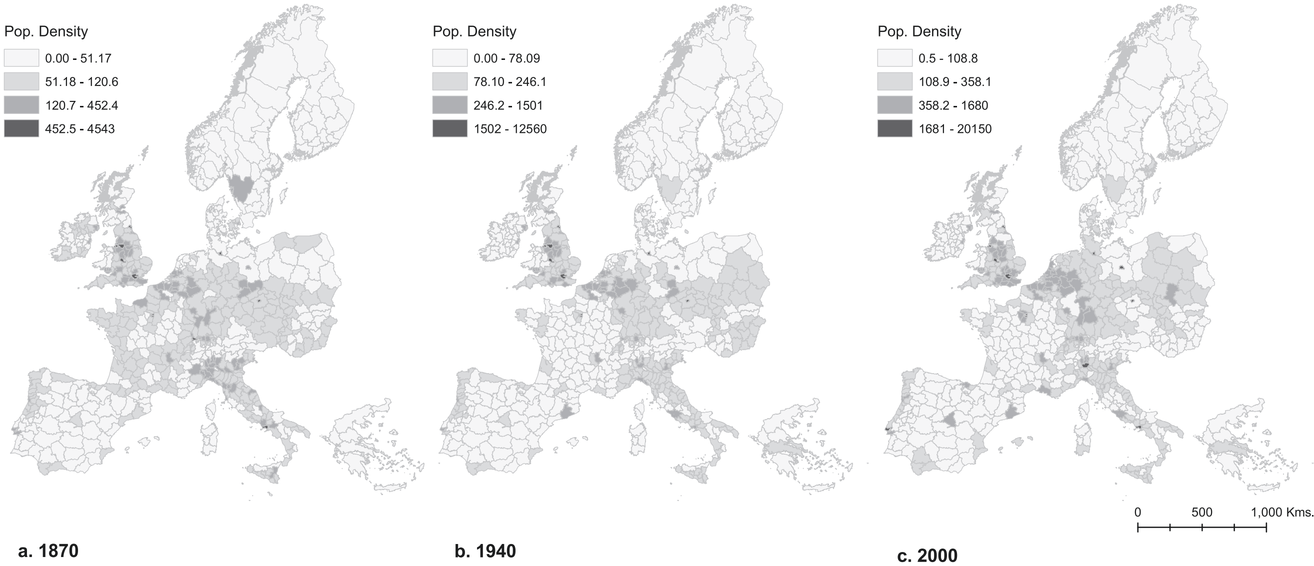


Fig. 6.4 Evolution of the population density in Europe. Constant regions

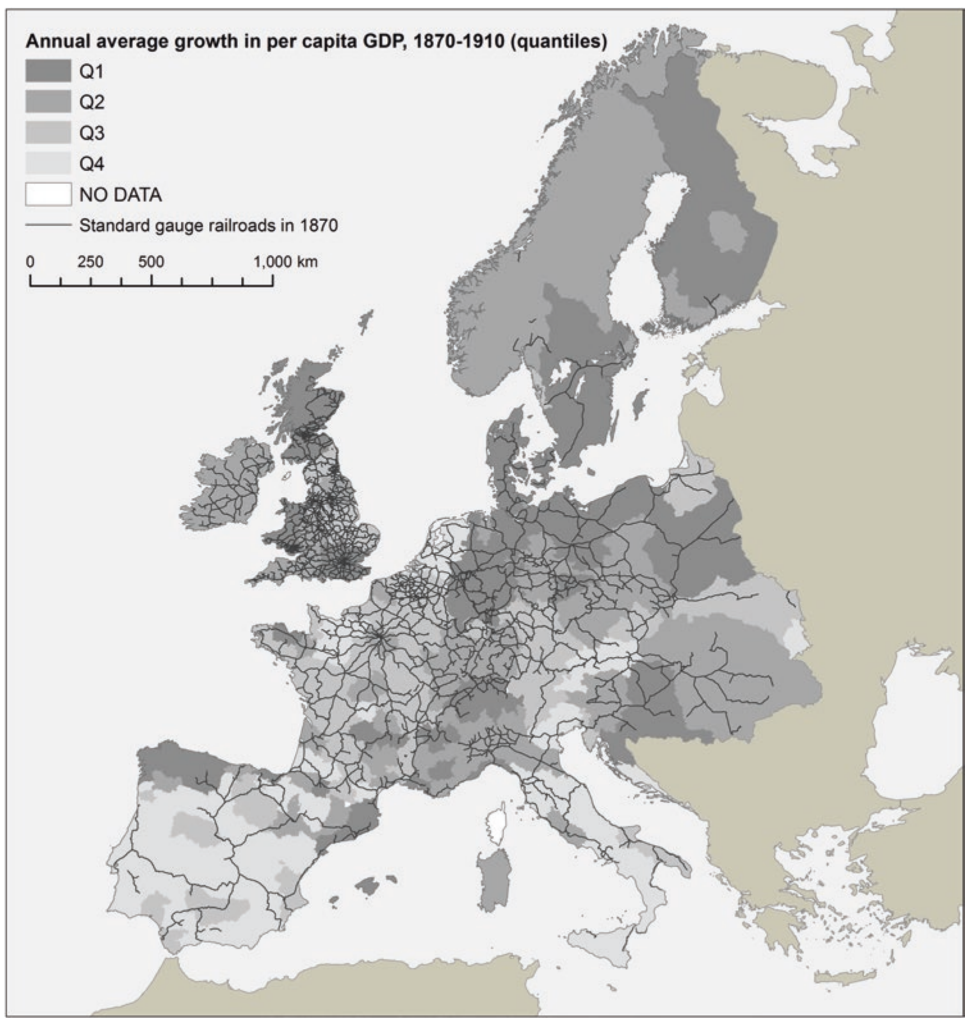


Fig. 6.5 Annual average growth in per capita GDP, 1870–1910 (quartiles)

and regional economic convergence took place, but in the subsequent period of stability, they returned and, in fact, increased.

This hypothesis has also been verified in the rest of Europe, and Díez-Minguela et al. have studied the factors that explain this process. The observed convergence can be explained by improved capital and market integration and, above all, by flows of labour from more marginal to core areas.

Specialists in regional imbalances claim that processes of convergence occur as a result of the homogenisation of both economic structures and labour productivity amongst regions. It should also be noted that public powers and their rebalancing policies do not appear to play a central role in this process.

In the next section, and in the tutorial for this chapter, greater emphasis will be placed on historical studies of inequalities at the local level. The originality here lies in the fact that for their study using GIS, we propose a different format and approach within the context of this book. As we shall see in greater detail in the tutorial, we will use the information available in OpenStreetMap (OSM) to geolocate previously prepared information relating to the streets of a chosen municipality. The interest of this approach lies in showing that social differences and differences in standards of living can be detected in studies involving a high level of detail or conducted at a large scale.

6.5 New Methods and Alternative Sources for Estimating Economic Inequality and Its Determinants: A Case Study of the *Comarca* of El Baix Llobregat (Catalonia), 1900–1950

In recent years, the study of inequality has gradually increased in social and historical scientific research. However, inequalities are not an abstract problem but rather an individual one. From a historical perspective, to reach this level of detail, it is necessary to create new databases, preferably at the micro-level. It is also necessary to establish a common thread between what we know about economic disparities at the macro-level and the characteristics of social inequalities at the micro-level. This challenge is a multi-dimensional issue that can be resolved through an inter-disciplinary approach which, amongst other features, involves using a spatial perspective. Over the last 20 years, economists have become more aware of the importance of using appropriate methods, such as decomposable indices of inequality, both within and between geographic units. Moreover, using contemporary data, several important advances have been made to align detailed georeferenced data with individual-level data, especially in the use of individualised neighbourhoods and multi-level analysis (Türk and Östh 2019).

However, such multi-dimensional efforts do not yet allow us to push back research over time. To do this would require using geographical characteristics as a source of variation, through which to study inequality from a historical perspective. This, however, entails the need to digitise materials such as maps, atlases, and census data (Pignataro 2021). The lack of suitable data for a more detailed analysis of socio-economic inequality and its determinants is particularly evident when dealing with historical periods. Despite recent improvements in the literature referring to economic inequality in the past (e.g. Alfani 2015; Milanovic et al. 2011; Piketty 2015), many relevant aspects of past societies, such as their individual sociodemographic characteristics (age, gender, household size and/or family composition) remain largely unknown. An assessment and combination of different sources, besides the most traditional fiscal ones, may offer a valid alternative for studying inequality in the past. This chapter proposes a combination of demographic and alternative fiscal sources, allied with novel statistical approaches, as an example of how we might advance in the study of socio-economic inequalities.

Recent studies have provided evidence of how higher levels of inequality would have hampered the creation of new opportunities by reducing intergenerational income mobility (Andrews and Leigh 2009; Björklund and Jäntti 1997). This caught public attention through the so-called Great Gatsby Curve (Krueger 2012). However, as previously mentioned, these views are only really relevant at the macro-level and tend to treat individuals as merely passive agents within this general process.

Several studies have measured how economic inequality has shaped social mobility and the unevenness of opportunities. Along these lines, several academics have shown that more unequal societies have less social fluidity (Hertel and Groh-Samberg 2019). This could be because more advantaged individuals and/or families are able to use a series of mechanisms that enable them to maintain their status and avoid downward mobility. In effect, this would tend to limit the chances of social mobility (Erikson and Goldthorpe 2002).

6.5.1 Motivation and Aim

The aim of this section is to conduct a methodological exercise. First, we present two different sources: one purely demographic and the other with fiscal components. Their combination could offer a valid alternative for studying the sociodemographic determinants of economic inequality. To do this, we use rich micro-level data for the *comarca* (local district) of *Baix Llobregat*, in Catalonia, for the period between the end of the nineteenth century and the first half of the twentieth century.

Next, we introduce an income imputation approach based on demographic and socio-economic characteristics, which we use to create an enriched database. We combine the best of demographic sources (e.g. longitudinal data, complete information at the household level) with economic variables. Certain economic variables, such as income, are not usually included in traditional demographic sources (e.g., censuses and population registers). In order to evaluate our imputation method, we then evaluate it using several different indicators of economic inequality.

Finally, we apply a recently developed tool from econometrics to decompose economic inequality based on its determinants. We then assess which sociodemographic characteristics, at the household level, had the greatest and least impact on increasing or reducing socio-economic disparities. We hypothesise that individuals are active agents who may, at least partially, influence economic inequality. Such influence can be operationalised (whether by mitigating or exacerbating it) net of social status. Therefore, individuals' small contributions may, when added up, have a significant effect on overall inequality.

6.5.2 Sources: The Baix Llobregat Demographic Database (BALL)

The BALL database currently compiles the population registers (*Padrón de habitantes*) of 13 municipalities in the *comarca* of El Baix Llobregat (in the province of Barcelona) and the personal tax records (*Cédulas personales*) of eight of the municipalities in this same *comarca*, corresponding to the nineteenth and twentieth centuries. This chapter will focus on five of these municipalities for which we have complete data covering the period 1828–1940. These population registers contain almost the only municipal census data (*Padrón de habitantes*) that have been conserved at the individual level available in Spain. The original national census data were generally destroyed, by legal imperative, once population numbers had been estimated, and cross-tabulations were made between the most relevant variables. Municipal or local censuses were first compiled in 1823.

The main purpose of the municipal censuses was to meet the military and fiscal requirements of the State, provide proof of residence in a given municipality, and register its number of inhabitants. From 1870 onwards, it was decided to make new local censuses at 5-year intervals. This was a practice that subsequently became well established from the beginning of the twentieth century. The first population censuses were simply lists of inhabitants. They only become full registers from the end of the 1830s onwards. They usually recorded the first name and surnames, age or date of birth, marital status and occupation of each individual. They also included information about the family and/or the working relationship of the different members of each household, the head of the household and the complete address. For some periods and municipalities, there was also information about the level of literacy, migratory status and income of the individuals. This was the case of the 1924 collection of municipal censuses, in which the number and type of variables were standardised for the whole country (García Ruipérez, 2012). However, this information was not compiled either completely or continuously, with it varying from population register to population register and from place to place.

Individual examples of national census returns have been found for several municipalities in El Baix Llobregat and have also been included in the BALL database (see Table 6.1). This implied including an increased number of individual observations in the BALL, particularly from the twentieth century onwards. The first modern national census conducted in Spain was carried out in 1857. This was followed by the national censuses of 1860, 1877, 1887, 1897 and 1900. They were subsequently carried out once every ten years (1910, 1920, etc.) until 1970. The State sponsored them with an important collaboration from local administrations until the late nineteenth century (Salas-Vives and Pujadas-Mora 2021). These documents were characterised by their universality, individual enumeration, simultaneity of data collection, periodicity, publication and diffusion (Goyer and Draaijer, 1992), which set them apart from previous attempts to gather such data.

Personal tax registers (*Cédulas* personales) were established in 1854, initially taking the form of a capitation tax. Until 1943, this was accompanied by the issuing of a personal identification document, which was subsequently replaced by the current national identity document. This was important within the creation of a liberal tax system (Marín Corbera 2010). The data source was initially called the *cédula de vecindad* (neighbourhood certificate), then later the *cédula de empadronamiento* (registration certificate), and finally the *cédula personal* (personal certificate) (Martín Niño 1972). The census structure adopted was similar to that used for population registers: it gathered personal, occupational and fiscal information about all citizens aged 14 and over residing in each municipality, including their address, and was completed on an individual basis. The preparation of collection lists, and indeed tax collection itself, was a municipal responsibility, as was that of compiling population registers. This is a source that has been little used to date in Spain and even less so in association with population registers.

In 1870, three different personal tax brackets were established, but the tax itself was abolished in 1873 (Melis Maynar 2019). It was then reinstated, in 1874, with 9 different tax brackets, which were extended to 11, in 1884. From 1874

Table 6.1 Years covered by the BALL database, 1828–1950

Municipality/source	Reference year															
Castellví de Rosanes																
Municipal censuses	1866	1924	1930	1936	1940	1945	1950									
Personal taxes																
Collbató																
Municipal censuses	1880	1889	1896	1900	1905	1910	1916	1920	1924	1930	1936	1940	1945	1950		
Personal taxes	1878	1879	1880	1881	1885											
Santa Coloma de Cervelló																
Municipal censuses	1901	1924	1936	1940	1945	1950										
Personal taxes	1910	1916	1920	1924	1929	1935										
Sant Feliu de Llobregat																
Municipal censuses	1828	1833	1838	1839	1857	1878	1881	1889	1906	1910	1915	1920	1924	1930	1936	1940
Personal taxes	1868	1882	1890	1891	1907	1909	1912	1916	1918	1924	1929	1935	1937			
Sant Vicenç dels Horts																
Municipal censuses	1921	1925	1930	1935	1940	1946	1950	1955								
Personal taxes	1879	1880	1881													

onwards, new tax brackets were established based on the amount of direct tax paid on real estate and/or industrial activities, annual salaries (but not wages paid to labourers on a day-to-day basis) and annual housing rents (Pérez Hernández 2020). After the reform of 1881, which coincided with our period of study, every individual who had to pay taxes was classified by the category in which they qualified to pay the greatest amount. The extremely poor, those living in cloistered religious communities, prisoners and troops were exempt from tax payment. Career military personnel were also given special consideration. It is worth mentioning that both active and inactive women fell into a single category. This makes using economic data referring to them both difficult and unadvisable. In contrast, men were represented in all the different tax categories.

For the imputation exercise carried out in this chapter, we used information on personal taxes for one medium-sized town (*Sant Feliu del LLobregat*) between the years 1880 and 1924. We used this to impute income, based on municipal census data, for *Sant Feliu*, and also for other four other municipalities located in the same *comarca*, for the period between 1880 and 1950. All these municipalities were closely located and in the same *comarca*, which ensured similar social and geographic contexts. Throughout the period studied, *Sant Feliu* (the *comarca's* capital)) was the town with most inhabitants in the *comarca* and had a mixed urban typology, including rural areas (Carbonell-Porro 1995). The other municipalities studied were more or less rural in nature. In fact, three of them, *Collbató*, *Castellví de Rosanes* and *Sant Vicenc dels Horts*, were mainly agricultural. *Santa Coloma de Cervelló*, on the other hand, had – like *Sant Feliu* – experienced quite a strong process of industrialisation since the end of the nineteenth century.

6.5.3 Methodology

6.5.3.1 Occupational Variables

The analysis carried out for this chapter required a series of methodological steps that involved working with both of the main data sources: municipal, or local, censuses (*Padrón de habitants*) and personal tax registers (*Cédulas personales*). Accordingly, one of the most important variables used to impute income, and which was recorded in both sources, was occupation. The information on occupations contained in these municipal censuses and personal tax data was mainly registered for the period from 1880 to 1950 and related to men and boys who were at least 14 years old and who lived in the five municipalities. Given the administrative nature of both sources, the occupational structure usually represented the whole occupational reality of the municipalities studied. The data available included information about occupations with a relatively low social status, such as unskilled urban and rural workers and day labourers, but also about individuals with much higher social and economic statuses, such as those employed in professionals and rentier property owners.

The ability to represent the whole of the occupational structure is one of the most valuable advantages provided by the sources used. This is especially the case with respect to personal tax registers, as other fiscal sources usually exclude individuals from both the top and bottom ends of the income distribution continuum, on the basis of either non-compliance or exemption. This can result in either the *over*- or *under*-estimation of economic inequalities (Prados de la Escosura 2008). However, one significant drawback to using these sources for reporting, and which is common to most historical socio-demographic sources, is their almost total failure to register female employment. This information is usually reported as "missing" or is referred to in very vague terms such as "household labour". One aspect that particularly failed to reflect the participation of women in the labour market was the deliberate omission of references to then doing paid work (Humphries and Sarasúa 2012).

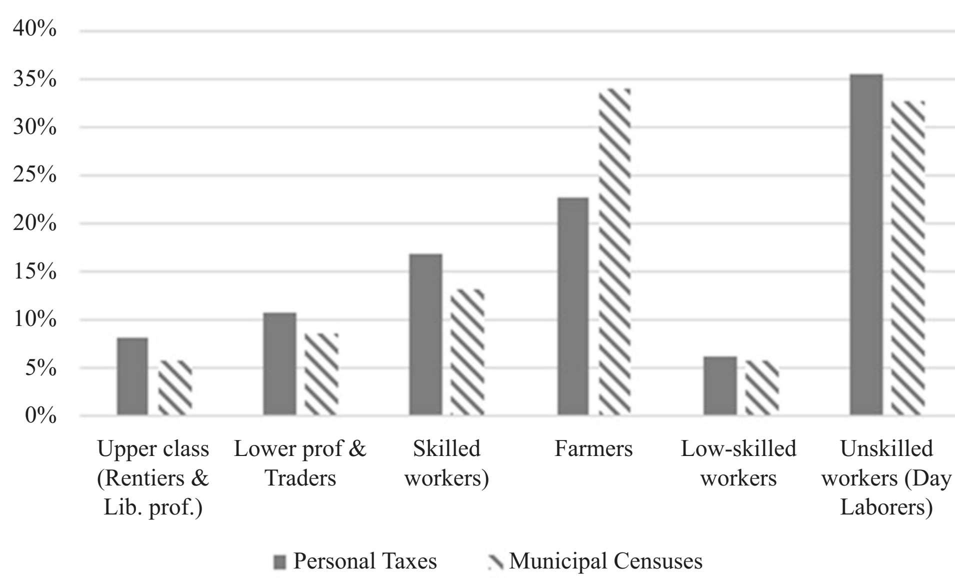
To best address the socio-occupational information obtained from the two sources, we first conducted the painstaking task of harmonising the different types of occupation. Next, we codified them using the Historical International Classification of Occupations (HISCO). This classification makes it possible to carry out a specific codification based on a historically adapted version of the ILO's ISCO68 (Van Leeuwen et al. 2002). In our case, using this historical classification facilitated the task of processing occupations that existed before the 1950s. After their codification, the resulting HISCO occupations were also classified according to two international schemes for social stratification that are widely used with historical data: HISCAM and HISCLASS (Lambert et al. 2013; Van Leeuwen and Maas 2011). The former provides a ranking from 0 to 99, in which the most advantaged occupations receive the highest scores and an individualised score is assigned to each occupation. The latter, on the other hand, establishes social categories based on degrees of skill; it also makes more classical divisions, such as that between manual and non-manual occupations.

As can be seen from Fig. 6.6, the distribution of social groups, classified using HISCLASS for both sources (Local Censuses and Personal Taxes) from 1880 to 1924, showed similar structures. This was an important asset for validating income imputations, as will be later explained. From 1880 to 1924, the overall structure exhibited a substantial presence of unskilled workers (mainly day labourers) and farmers; they accounted for more than 50% of the total distribution of occupations. Overall, the distribution of occupations across the different social groups coincided between the two sources: the municipal census data for the five different municipalities and the personal tax register data for *Sant Feliu*. It is only in the case of farmers that we find an over-representation of this particular occupational group in the municipal census source compared to the personal tax register. Such a difference could perhaps have been expected, for while data on personal taxes were only available for *Sant Feliu*, those obtained from the municipal censuses covered different years and related to four other municipalities, some of which were predominantly rural in character. Figure 6.7 shows the percentage of farmers amongst the working population according to the various municipal censuses conducted between 1880 and 1950 in the five municipalities. It can also be seen that while farmers accounted for the vast majority of the working population in *Collbató* and *Castellví,* they generally accounted for less than 20% of the working population in *Sant Feliu* and *Santa Coloma de Cervelló.*

6.5.3.2 Variables in Personal Tax Data

One of the principal aims of this section was to apply imputation methods in order to assign economic variables relating personal tax to municipal census data. To do this, we first had to assess the different income variables present in the personal tax data available for *Sant Feliu* between 1880 and 1924. To be more specific, we had to analyse nine different sets of personal tax data relating to this period (for the years 1880, 1881, 1891, 1907, 1909, 1912, 1916, 1918 and 1924). The economic variables contained in these personal tax data were of three different types. They were based on information about direct taxes paid on real estate or industrial activities (referred to as *contributions*), annual salaries (for

Fig. 6.6 The distribution of social groups, classified using HISCLASS for both sources (Local Censuses and Personal Taxes) from 1880 to 1924



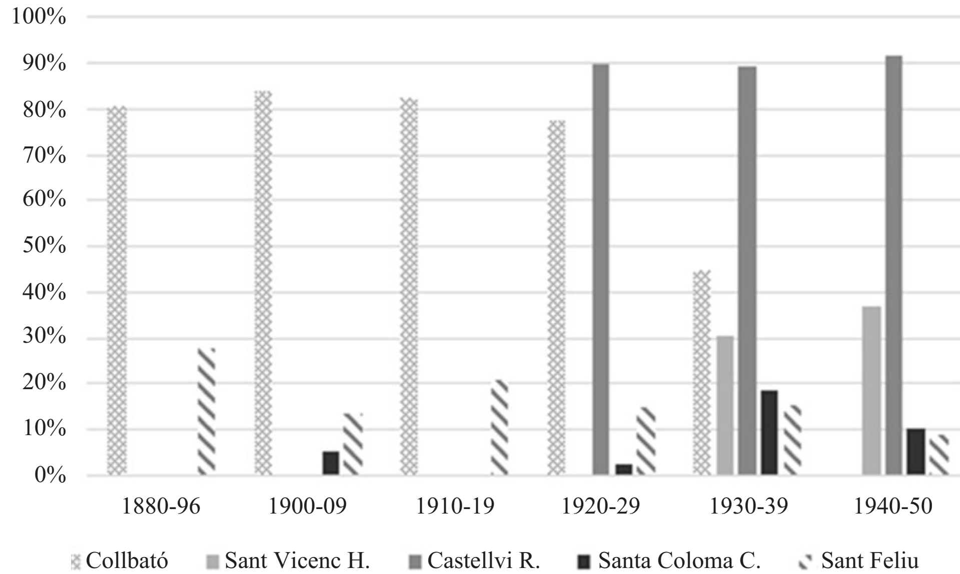


Fig. 6.7 Percentage of farmers amongst the working populations of the different municipalities (1880–1950)

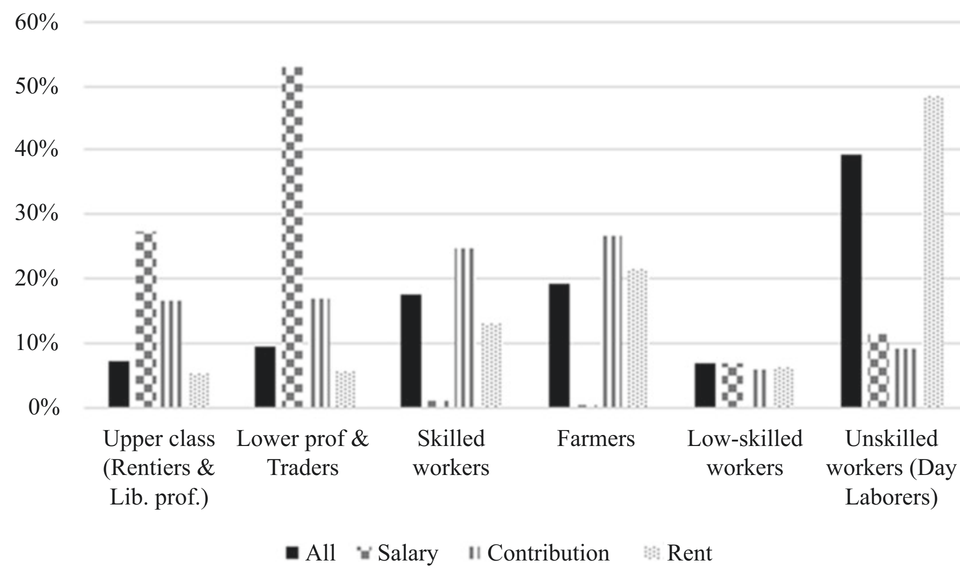


Fig. 6.8 Percentage of different social groups reporting income from salaries, contributions and/or rent in their personal taxes (1880–1924)

workers with all-year contracts, rather than day-by-day labourers) and annual housing rents (Pérez Hernández, 2020). This information could have been registered for anyone over 14 years old but was largely to be found for adult males identified as heads of households (HH). Individuals were usually registered based on just one of these three economic variables, normally that of the highest value. If individuals did not have any declared source of income (*contribution*, salary or rent), they generally paid a smaller amount, based on their reported occupation.

These three economic variables presented different, and yet complementary, information about the overall financial capacity of the population. *Contribution*s from real estate or industrial activities could be regarded as providing information about *wealth*. Salaries came closer to the classic concept of income. Information about rent provided information about how families could have spent their income. We were therefore able to observe the socio-occupational distribution of all of the heads of households for which there was personal tax data for the period between 1880 and 1924 and to compare this with the distribution for those corresponding to only one of the three economic variables (*contributions*, salary and rent). As a result, we were able to observe an uneven allocation of both *contributions* and salaries. In Fig. 6.8, it is possible to see that while the overall socio-occupational distribution showed a monotonic increase, ranging from the highest status groups (less than 10% in the case of the upper class) to that of unskilled workers (40%), the share of those who received salaries or *contributions* was different.

For instance, around 27% of the heads of households for whom we have salary-related information belonged to the upper class, while 50% of the distribution of salaries related to lower-level professionals and traders. However, amongst those paying taxes on real estate and on industrial activities (*contributions*), the share was more evenly distributed. Even so, 40% were skilled workers and farmers. This is something which we might have been expecting, as there were usually fewer individuals earning annual salaries in these groups at that time. Finally, half of the total number of individuals for whom there is data about rent were apparently unskilled workers (labourers working on a day-by-day basis). This considerable accumulation of rent amongst the unskilled worker groups corresponded to the nature of their activity, with income being much less regular and harder to achieve. On the other hand, information about their expenditure was easier to access.

We can see from Fig. 6.3 that of those receiving salaries and *contributions*, around 10% were unskilled workers. This means that the two different economic variables relating to income (salary) and wealth (*contributions*) were present in all of the different socio-occupational groups; this is a factor in favour of their economic imputation. When we calculated the percentage difference between the overall socio-occupational structure with regard to personal tax payment, and each of the different economic variables (which were usually only paid by heads of household), we saw that it never either over- or under-represented the distribution of occupations by more than 40% (see Fig. 6.9).

6.5.3.3 Total Income Imputation

We used salaries and contributions as proxies for income and wealth to impute economic variables from personal tax data into municipal census data. We used predictive mean matching methods (PMM) rather than parametric multiple imputation (MI) in order to conserve the original distribution of the empirical data when they were not normally distributed. This is usually the case with data on income and wealth (Kleinke, 2017). PMM combines standard linear regression with a nearest-neighbour imputation approach. We used linear regression to obtain predictions of income and wealth, which were then used as a measurement of distance, in order to derive a set of the ten nearest neighbours, which were individuals for which there were complete values. We then randomly obtained a value from this set.

The first step was to (separately) estimate a linear regression for both salaries and *contributions*, using the SES scale (HISCAM) and age as dependent variables. We also added a control to the regression, in the form of a reference year, for both the municipal census and personal tax data.

$$Y\left(\text{salary or wealth}\right)_i = b\left(\text{HISCAM}\right)_i + b\left(\text{Age}\right)_i + b\left(\text{Year of reference}\right)_{it} + e_i$$

After running the regression, we predicted the salary and *contribution* values, based on the estimated coefficients for each cell (for individuals, with both missing and non-missing income). The last step was to impute the missing income (from the municipal censuses) to individuals and to attribute

Fig. 6.9 Differences between the share of income individuals reported from salaries, contributions and/or rent, in comparison to the total distribution of income reported by different social groups in their personal taxes (1880–1924)

the actual income and wealth data relating to these same individuals to the closest predicted results from the regressions for personal tax payments. In this case, one of the main strengths of PMM is the use of real income and wealth data and not that of randomly generated values.

Once the imputation for both salaries and *contributions* had been done, we created a total income variable for individuals related to municipal census data; this was obtained from the sum of the imputed salaries and *contributions*. The rationale behind this was to provide potentially complete economic information for all adult males (who were usually heads of households), based on their occupational and age profiles, covering a number of different years. After creating the total income information, we derived a definitive variable for total annual family income. Accordingly, we calculated the equivalised family income for each family (*j*), in a given year (*t*), for each municipal census, by first scaling the sum of family income and then dividing it by the square root of the sum of all the individuals in the same family who formed part of the same household. We included all families, regardless of whether they had children or not. This equivalence method follows the OECD guidelines adopted for most studies that examine family poverty and economic inequality (OECD 2011).

$$\text{Equivalized family income}_{jt} = \Sigma(\text{income})_{jt} \,/\, \sqrt{[}\Sigma(\text{size})_{jt}$$

Using the complete imputation method and generating total family income allowed us to optimise the information available. This provided us with economic information relating to almost 14,000 households between 1880 and 1950. This was based on municipal census data for the five different municipalities located in the *comarca* of *Baix Llobregat*. Table 6.2 shows the years with personal tax data presented in columns; these were used as references for each year for which data were available from the municipal censuses (presented in the rows). The individual cells present information derived from each individual observation and show valid total family income: 65,872 references out of a total of 75,872, for all the available years for which personal observations were registered in the municipal census under study.

6.5.3.4 Measures of Inequality and Recentered Influence Function Regressions on the Factors That Determine Inequality

We evaluated the method for imputing total family income in two different ways. First, we computed several measures of economic inequality: the Gini index; the share of total family income accumulated by the top 1% and 10% of the population; the share concentrated in the poorest 40%; and the Palma Ratio, which is the ratio of the share of the top 10% divided by that of the bottom 40%. All of these indicators are common standards within the main literature on economic inequality. The measurements were computed on a yearly basis for each municipal census decade (between 1900 and 1950), both for the *comarca* of Baix Llobregat and at the individual municipality level.

After assessing the descriptive economic inequality in *Baix Llobregat*, we investigated the role that different sociodemographic variables could have had in potentially reducing and compensating inequality at the family level in each census period. To do this, we applied recentered influence function (RIF) regressions, which are preferred for decomposing *contributions* to economic inequality (measured with the Gini Index). RIF regressions were developed by Firpo, Fortin and Lemieux (2018) and have been increasingly used in economic studies of inequality and wage distributions. This method makes it possible to estimate the impact of small changes in covariates on the dependent variable's entire (unconditional) distribution (the Gini index). It offers an intuitive methodology that can be applied to a standard OLS regression. Here, we used it to discover the main demographic characteristics that contributed, either positively or negatively, to overall inequality:

$$RIF(y;v) = v(F) + \mathrm{IF}(y;v)$$

where in a distribution of y_{ith}, ordered in a cumulative distributive function, v (F) is a distributional statistic (Gini.) and IF $(y;v)$ is the influence function associated with v (F).

$$\mathrm{IF}(y;v)\,dF(y) = 0$$

is the average of the directional derivatives of each small change (y_{ith}) in the distribution function; the RIF regression is similar to the standard OLS regression except that it replaces the dependent variable, income, with the recentered influence function: RIF (y:G), which in our case was a measure of inequality, the distributional Gini (G) of income. It was therefore possible to model it as:

$$E\left[RIF_t(Y;G)\mid X\right] = X\beta_{jt}$$

where X_{it} is the set of explanatory variables relating to the sociodemographic characteristics measured for each family and in each year.

6.5.4 Results

To evaluate our imputations, we first individually computed the yearly Gini indexes for all the municipalities in *Baix Llobregat* for the period from 1880 to 1950. As shown in Fig. 6.10, we observed a decreasing trend in inequality from the beginning of the twentieth century until the 1950s. This

Table 6.2 Years corresponding to the presentation of personal taxes at *Sant Feliu*, used to impute income corresponding to municipal censuses of five different municipalities and the total number of individuals with imputed income in each year, based on municipal censuses (1880–1950)

		Years with personal tax data for *Sant Feliu*									
		1880	1881	1891	1907	1909	1912	1916	1918	1924	Total
Years with municipal census data for the five municipalities	1880	771	0	0	0	0	0	0	0	0	771
	1881	0	2929	0	0	0	0	0	0	0	2929
	1889	0	0	2557	0	0	0	0	0	0	2557
	1896	0	0	680	0	0	0	0	0	0	680
	1900	0	0	693	0	0	0	0	0	0	693
	1901	0	0	540	0	0	0	0	0	0	540
	1905	0	0	0	661	0	0	0	0	0	661
	1906	0	0	0	3586	0	0	0	0	0	3586
	1910	0	0	0	0	4549	0	0	0	0	4549
	1915	0	0	0	0	0	4162	0	0	0	4162
	1916	0	0	0	0	0	0	724	0	0	724
	1920	0	0	0	0	0	0	0	4860	0	4860
	1921	0	0	0	0	0	0	0	2043	0	2043
	1924	0	0	0	0	0	0	0	0	7507	7507
	1930	0	0	0	0	0	0	0	0	8303	8303
	1935	0	0	0	0	0	0	0	0	3026	3026
	1936	0	0	0	0	0	0	0	0	8844	8844
	1940	0	0	0	0	0	0	0	0	6542	6542
	1945	0	0	0	0	0	0	0	0	1388	1388
	1950	0	0	0	0	0	0	0	0	1507	1507
	Total	771	2929	4470	4247	4549	4162	724	6903	37,117	65,872

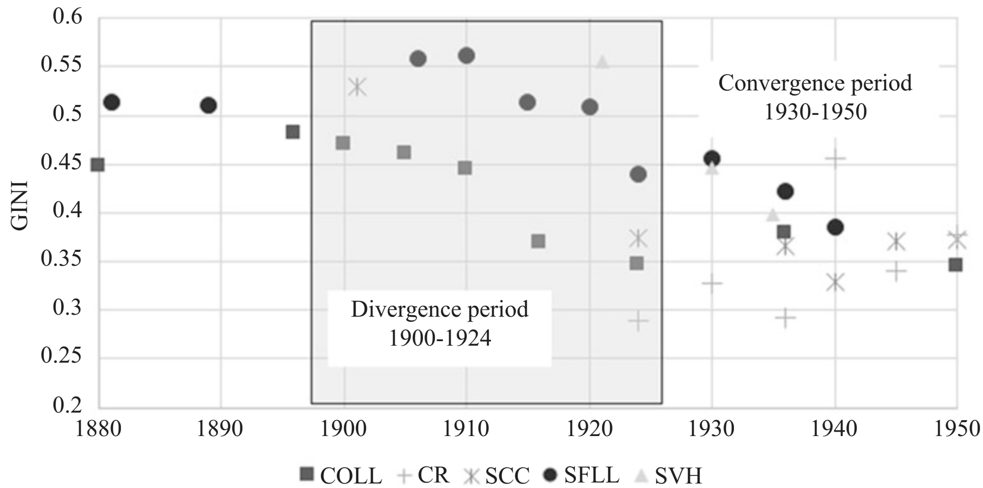


Fig. 6.10 Gini index of total imputed family income (Salary + Contribution) in Baix Llobregat, by municipality (1880–1950)

trend largely coincided with those observed in previous studies using the Gini index for the same period that used aggregated data for Spain at the national level (Prados de la Escosura 2008). These results showed the accuracy of these imputations and justified the choice of the PMM methodology for analysing social and economic disparities. As Modalsli (2015) points out, even when studies use real mean income or wealth data to estimate values, as in "social tables", they often underestimate the levels of inequality measured by Gini indexes. This is a pitfall that our imputations were able to avoid.

Next, in Fig. 6.10, it is possible to observe the results territorially (although the years for which municipal censuses were available differed from municipality to municipality). In this case, we were also able to confirm some findings from other historical inequality studies. In this regard, especially for the period 1900–1924, the estimated inequality was much greater for Sant Feliu (SFLL) than for Collbató (COLL), the two municipalities with the highest registered populations over time. This difference showed an already-known higher incidence of inequality amongst more urbanised (SFLL) territories than rural ones (COLL); this is something that had already been observed for other historical periods (Alfani 2015; Brea-Martínez and Pujadas-Mora 2018). The first period could therefore be labelled as one of divergence in inequality, particularly between urban and rural areas. However, from the 1930s onwards, we observed a tendency for convergence in the inequality present in all five municipalities. This was reminiscent of the effect of greater economic and labour market integration (Rosés et al. 2010).

We homogenised the data to include the general patterns for all five municipalities, decade by decade, and observed a continuous decline in inequality in all the indicators used for the period from 1900 to 1950 (See Table 6.3). First, following the Gini index, decade by decade, in the *comarca* of *Baix Llobregat*, we observed that inequality decreased by 20% in 50 years, with the Gini index for total family income moving from a high rate of 0.57 to a medium-high rate of 0.38.

Interestingly, when we observed the total accumulated income between the richest (top 1% and 10%) and poorest (bottom 40%) sections of the households, we noted an equalising process over time. While in the decade 1900–1909, the wealthiest 1% accumulated 11% of total income, the poorest 40% had only 6%, and this latent inequality was even more evident when we observed the 41% accumulated by the top 10% richest families. However, this process progressively reverted over time, and by the 1940s, the difference between the richest and poorest was much narrower. The Palma ratio, which shows the ratio between the share of the richest 10% divided by that of the poorest 40%, showed a reduction in inequality over time. Thus, in 1900–1909, the Palma ratio for Baix Llobregat was 6.83, which was similar to that of South Africa, which was one of the most unequal countries in the world, at the time. However, the ratio of 1.6%, corresponding to the 1940s, was closer to the Palma ratio found in many developed societies in Western Europe today.

Finally, the main advantage of having a complete database containing a full range of sociodemographic and family characteristics and of total income information lies in the possibility of measuring inequality and decomposing it. This makes it possible to discover the determinant reasons behind its reduction or increase. This type of information can provide significant historical information for policy-makers and for academic and non-academic purposes.

Table 6.4 shows the results of RIF regressions, run by decades, for the *comarca* of Baix Llobregat, regressing the recentered influence function of the Gini index for different socio-demographic variables at the family level and using these as independent variables. These regressions were interpreted as an OLS regression. As a result, we were able to capture the potential increase or decrease in inequality for each unit of change in the independent variables. Analysing

Table 6.3 Different measures of inequality in total family income (salary + *contribution*) in the *comarca* of Baix Llobregat (1900–1950)

N = 13,948 families	Inequality in total family income in Baix Llobregat				
Decades	Gini	Top 1%	Top 10%	Bottom 40%	Palma ratio
1900–1909	0.57	11%	41%	6%	6.83
1910–1919	0.52	9%	37%	8%	4.63
1920–1929	0.49	8%	34%	10%	3.40
1930–1939	0.42	6%	32%	15%	2.13
1940–1950	0.38	5%	29%	18%	1.61

Table 6.4 Recentered influence function (RIF) regression on the sociodemographic determinants of total family income (salary + *contribution*) inequality in the *comarca* of *Baix Llobregat*, by decades (1900–1950)

	1900–1909	1910–1919	1920–1929	1930–1939	1940–1950
Gini	m1900	m1910	m1920	m1930	m1940
Age of the HH	−0.001	−0.005***	−0.001	0.000	0.000
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Size of household	−0.022	−0.012	−0.021**	−0.015*	−0.012
	(0.013)	(0.009)	(0.007)	(0.007)	(0.009)
No of children	0.008	0.017	0.031***	0.004	0.013
	(0.012)	(0.010)	(0.008)	(0.008)	(0.010)
No of elderly	0.056	0.094*	0.035	0.004	−0.016
	(0.093)	(0.043)	(0.026)	(0.016)	(0.022)
Skilled worker HH (ref)					
Upper class	0.069	0.017	0.023	0.194*	0.090
	(0.147)	(0.090)	(0.083)	(0.084)	(0.064)
Lower prof and trader	−0.093	−0.217***	−0.067	0.037	0.028
	(0.070)	(0.041)	(0.044)	(0.030)	(0.040)
Farmer	0.039	−0.041	−0.025	−0.013	0.000
	(0.046)	(0.024)	(0.026)	(0.016)	(0.031)
Low-skilled worker	0.075	0.023	0.086*	0.032	0.013
	(0.059)	(0.037)	(0.038)	(0.020)	(0.021)
Unskilled worker	0.195***	0.176***	0.098**	0.066**	−0.026
	(0.055)	(0.034)	(0.033)	(0.024)	(0.021)
SES (HISCAM) HH	0.014*	0.014***	0.009**	0.003	0.005
	(0.006)	(0.003)	(0.003)	(0.002)	(0.002)
Urban	−0.021	0.008	−0.084***	−0.004	−0.048
	(0.041)	(0.028)	(0.021)	(0.015)	(0.055)
Extended family (ref)					
Nuclear family	0.055	0.052*	−0.018	0.001	−0.018
	(0.041)	(0.022)	(0.019)	(0.014)	(0.020)
Other households	−0.012	−0.049	0.001	0.008	−0.027
	(0.069)	(0.042)	(0.032)	(0.028)	(0.068)
N	997	1661	2500	3666	2071
adj. R^2	0.079	0.152	0.062	0.034	0.033

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

more than 10,000 families included in the regressions for the period between 1900–1909 and 1940–1950 (see Table 6.2), we were able to observe which social groups had the highest coefficients. This was especially relevant for unskilled workers in the period between 1900 and 1939, as each (1%) unit increase in the share of unskilled workers was associated with a potential increase in inequality. We also observed important influences from other variables. For instance, the older the head of household, the lower the inequality, and the higher the SES status of the head of household, the lower the inequality.

However, the best way to interpret the potential reduction, or increase, in inequality deriving from changes in the dependent variables is based on its percentage change. This can be done by dividing the coefficient of a particular dependent variable, in a given year, by the Gini Index for the same year. Table 6.5 shows all the percentage changes relating to the potential reduction or growth in inequality for a one unit increase in each dependent variable. The coefficients shown in bold relate to the variables that were statistically significant to at least the 90% level. Examining each variable in order, we see a negative relationship between the age of the head of the household and inequality. Accordingly, for each additional year of age of the head of household, the Gini index decreased by 1% during the period 1910–1919. These results aligned with the fact that families headed by younger individuals were usually the ones in the poorest part of the income distribution.

Conversely, and contrary to what would be expected nowadays, the larger the household, and the more children it contained who were under 14 years old, the greater the potential was to reduce inequality; this had a reductive impact of almost 4%. These results have to be put into context, however, because child labour was still common in Spain, especially in more rural areas, until the first half of the twentieth century. As a result, an additional child would have meant extra potential labour and income. Similarly, it is possible to see the contrary for each additional elderly person (above 75 years old) in each household; there was an important increase in inequality, of up to 17% according to the Gini Index, especially for the more distant historical periods (1900–1929). These results should also be read from a demographic perspective. In the earlier periods, life expectancy was lower, and the health conditions of older individuals were worse. For a family, this meant not only less labour but

Table 6.5 Percentage change in the Gini index of total family income by the different dependent variables displayed in the RIF regressions

	1900–1909	1910–1919	1920–1929	1930–1939	1940–1950
Age of the HH	0%	**−1%**	0%	0%	0%
Size of household	−4%	−2%	**−4%**	**−4%**	−3%
No of children	1%	3%	**6%**	1%	3%
No of elderly	8%	**17%**	7%	1%	−4%
Skilled worker HH (ref)					
Upper class	13%	3%	5%	**47%**	23%
Lower prof and trader	−16%	**−40%**	−13%	7%	6%
Farmer	5%	−7%	−4%	−3%	1%
Low-skilled worker	11%	4%	**16%**	8%	4%
Unskilled worker	**33%**	**33%**	**20%**	**16%**	−5%
SES (HISCAM) HH	**3%**	**3%**	**2%**	1%	1%
Urban	−2%	−1%	**−16%**	−1%	−14%
Extended family ref.					
Nuclear family	10%	**10%**	−4%	0%	−5%
Other households	−1%	−10%	−1%	0%	−7%

Based on the regression coefficients, values that are statistically significant at least at 90% in bold

also an extra mouth to be fed. This could have had an impoverishing impact and therefore exacerbated existing inequality.

In Table 6.5, we observe the variables relating to the socio-occupational status of heads of households. It can be seen that the lower the social status, the greater the potential increase in the Gini index. For instance, by just adding an extra 1% of families headed by unskilled workers, the increase in inequality could be as much as 33%. On the other hand, increasing the share of upper class or lower professional class heads of household by 1% would have alleviated inequality by almost 50%. These results confirm that disparities in the occupational structure directly caused higher rates of inequality, as observed for the period 1900–1929, when the share of unskilled workers in all five municipalities was highest. However, inequality then decreased, particularly in the 1930s, in association with an increase in the availability of human capital, a fall in primary sector employment and greater labour market integration. We can also see how urban growth within a more modern occupational structure could have led to a reduction in inequality in the more recent periods.

Finally, and most interestingly for southern European patterns, as in the case of Catalonia, we were able to construct a variable that defined whether a family was nuclear, extended (mainly stem families) or neither (usually a household including lodgers or servants), based on municipal census data. In this regard, we see that when we used the extended family as a reference group, the higher the share of nuclear families, the greater was the inequality. This result sheds light on the crucial function that traditional extended families could also have had in the domestic economy. However, within the Catalan context of the first half of the twentieth century, and especially during its first decades (1900–1919), traditional Catalan families still used to be mainly extended in nature. The few nuclear households could have contained migrant labourers, who would usually have been poor. In fact, from the 1920s onwards, when there were higher levels of migration and a progressive "nuclearisation" of families, the Gini coefficients lost their statistical significance.

6.6 Conclusions

This paper presents new methods, based on the decomposition of data, to help understand the determinants of economic inequality. It does this by combining individual socio-economic and demographic information, using a new, ongoing database, which has been built by linking together information from population registers and fiscal sources.

Our findings show that inequality was greater in industrialised and urbanised municipalities, such as Sant Feliu de Llobregat, in the first decades of the twentieth century, than in more rural ones, like Collbató. However, the levels of disparity converged from the 1930s onwards, thanks to a greater degree of economic and labour market integration. It is worth noting that the overall trend was for inequality to decrease from the beginning of the twentieth century. Moreover, that between the top 10% and bottom 40% of the population decreased over time.

When decomposing the contributions of different social groups to inequality, we noted that unskilled workers played an important role in generating disparities. However, the improvement in human capital, which was mostly seen in the more industrial municipalities, brought with it a decrease in inequality, as would probably have been expected. On the other hand, with the rise of the nuclear family, which was particularly evident from the 1920s onwards, there was no longer such a beneficial effect, and inequality was not reduced in the way that it previously had been. This can be seen from the development of stem families, which were prevalent until that decade.

Finally, from a demographic point of view, households headed by elderly individuals tended to contribute less to inequality than those with younger family heads. However, older family members (who were not the heads of their households) were the ones who contributed most to increasing inequality; this is the opposite of what we tend to see nowadays. One potential explanation for this divergent pattern could have been the absence of a robust social security system and the almost total absence of old-age pensions at the beginning of the twentieth century. In this regard, elderly family members who could not work would not have contributed to their family's economy.

6.7 Tutorial

In this tutorial, we will study regional disparities at four different scales:

1. In the first exercise, we will work with indicators of gross domestic product (GDP) in Europe at the NUTS 2 region scale.
2. In the second exercise, we will look at a closer scale and work with the smaller NUTS 3 regions. In this case, we will study recent official data.
3. Then, we will work with smaller territorial units: judicial districts in Spain.
4. Finally, we will increase the scale and analyse regional disparities at the local scale.

Changing the scale does not only imply a numeric difference but also qualitative differences. In this respect, some topics can only be studied at a certain scale, because at others, their significance changes. For example, it is not possible to work with street-level data for all of the municipalities in Europe: the amount of work that this would entail would be immense, and it is not possible to run algorithms using such a large amount of information. As a result, it would be impossible to obtain and adequately present the results. Each scale (continental, national, regional and local) requires a different methodology and means of analysis. Furthermore, in each case, the data that can be used will also be different.

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Using Archival Aerial Imagery to Study Landscape Properties and Dynamics

7

Manel Llena and Damià Vericat

Abstract

Current advances in computer vision and photogrammetry allow extraction of high-resolution 3D topographic models and orthophotomosaics from digital images. Together, these allow for a much improved characterization of landscape properties and their evolution compared to older, more traditional photogrammetric methods. But can we benefit from some of these advances to use historical information such as archival aerial imagery to extend the temporal scales at which landscapes can be observed, analysed and understood?

In this chapter, we provide some examples to demonstrate how archival aerial imagery can be treated digitally to extract the information needed to study landscape forms at multiple temporal scales. First, we provide a general section highlighting the opportunities provided by archival information and how coupling historical with contemporary datasets allows for an improved understanding of landscape evolution. Second, we explain how we can integrate archival aerial imagery with geographic information systems (GIS) to allow analysis of landscape features of interest. To illustrate the value of this approach, we present a case study analysis of landscape dynamics; this case study uses archival imagery to assess land use evolution related to afforestation and land abandonment and assess multi-temporal topographic changes related to human disturbance. Specific methodological workflows to treat and analyse archival aerial imagery in order to extract information, together with a tutorial, datasets and required software, are provided as part of the chapter.

Keywords

Archival aerial imagery · GIS · Landscape · Structure from Motion (SfM) · Landscape properties and changes

7.1 Introduction

7.1.1 Context

New platforms, sensors, software and algorithms have revolutionised the temporal and spatial scales at which geographical information can be acquired. An example of this is the use of Structure from Motion Photogrammetry (SfM) that uses ground-based images or those taken by unmanned aerial vehicles (UAVs) or other platforms (e.g. Westoby et al. 2012; James and Robson 2012; Smith et al. 2015). SfM, together with Multi-View Stereo (MVS) algorithms, allows extraction of high-resolution 3D topographic models together with orthophotomosaics, which can be analysed to understand landscape evolution. We use the term SfM photogrammetry to refer to this. These advances provide a new paradigm, reflecting (a) 'speed' (photographs can be quickly acquired, i.e. less time involved on data collection), (b) 'cost' (the access to these techniques is relatively cheap compared with other that provide similar data) and (c) 'resolution' (we can

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survey large spatial areas on multiple occasions, providing repeated and detailed information that can be used to study changes).

The application of SfM photogrammetry to archival aerial imagery, together with the application of methodologies based on GIS and remote sensing approaches, offers a wide range of possibilities to study changes in landscape properties and topography through time. On the one hand, orthophotomosaics can be post-processed by the application of digital image classification for land use mapping; on the other hand, Digital Elevation Models can be compared for the estimation of topographic changes. The study of land use changes (including topographic and planimetric) is an obvious application of these methods.

7.1.2 Contents

The chapter aims to provide non-expert teachers, lecturers and students with guidance on spatial analysis using geographic information systems (GIS). It provides basic knowledge, guidance and materials to extract and analyse spatial information obtained from historical archival aerial imagery through Open Source GIS. Prior knowledge of GIS-based spatial analysis tools is not necessary, since all details are provided. The information provided can be used to characterise landscape properties and to understand long-term landscape changes, specifically (a) the evolution of land uses due to afforestation and land abandonment and (b) multi-temporal topographic changes related to human disturbance.

The chapter is divided into four main sections. First, a broad introduction to the opportunities that SfM photogrammetry applied to archival aerial imagery is presented. This section includes an overview of the methods ('workflow') used to assess land use and topographic changes through the analysis of geographic information derived from the application of SfM photogrammetry to archival aerial photographs. This overview is mainly theoretical. The second section includes a case study from which readers and end-users can learn about and are then able to apply these methods. The case study provides details of materials and methods, along with the main results and a brief discussion. Some of these results were presented by Llena et al. (2018, 2019). The third section provides some final considerations and take-home messages. This is followed by a detailed tutorial along with the data used in the chapter (Sect. 7.4); supplementary materials are also provided. Tutorial also includes a series of key questions designed to stimulate thought. The answers to these are provided in the study case section; the questions help ensure that the learning outcomes of the chapter are attained.

7.2 Applying SFM Photogrammetry on Archival Aerial Imagery

7.2.1 Opportunities

SfM photogrammetry allows extraction of 3D information and orthophotomosaics from multiple photographs. Extraction of 3D information is possible because each photograph is taken, looking at the scene or object of interest from a different position. Despite a wide range of SfM photogrammetric software being available to process images, most share a common methodological approach. This approach can be applied to archival aerial imagery, but it is necessary to follow a specific workflow. The main steps of this workflow are summarized and presented in Fig. 7.1. They are also described in greater detail by Llena et al. (2018). The first step consists in image alignment, which is achieved by the software searching for common points visible in several images. Then, the 3D geometry of the scene is estimated, including the coordinates of the common points, along with the position of the camera (i.e. extrinsic calibration) and the internal parameters of the camera (i.e. intrinsic calibration; Ullman 1979). The use of historical aerial photographs presents two main issues that may affect data accuracy and precision: (a) the overlap between photographs and (b) the quality of the image (Micheletti et al. 2015; Bakker and Lane 2017; Llena et al. 2018). In historical photographs, the quality of the image is often compromised during its storage or during the scanning process, leading to the loss of image quality (e.g. blurred areas, presence of artefacts), and a consequent increase in errors in the alignment process and, consequently, final 3D products. Through the alignment process, a first low-density point cloud is obtained, which must be georeferenced and scaled. The georeferencing and scaling process consists of the geometric and geographic correction of the sparse point cloud by the use of Ground Control Points (i.e. GCPs). The selection of GCPs is based on the location of coincident points from the photographs in potentially unchanged locations (e.g. road crossings, field boundaries) compared with available georeferenced information. It is important to avoid the selection of GCPs in elements with complex or irregular geometries since these irregularities may decrease the accuracy of the GCPs and introduce significant errors in the final point cloud.

The last step is the acquisition of derived products or geographic information. Here we refer to (a) point clouds and (b) orthophotomosaics. Once the sparse point cloud is georeferenced in a known coordinate system, the next step is to apply different algorithms (e.g. MVS) to increase the density of the point cloud by at least two orders of magnitude, obtaining a definitive dense cloud. Additionally, through the orthorectification process, a single orthophoto-

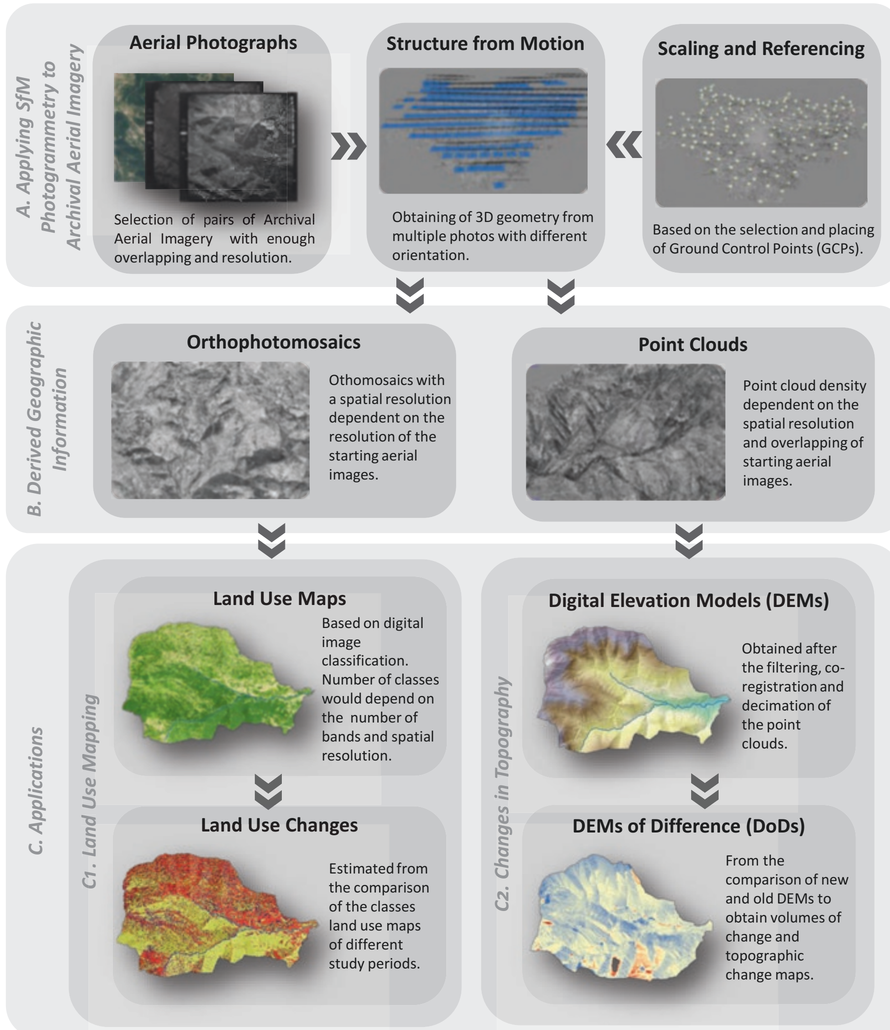

Fig. 7.1 Summary of the workflow followed to obtain orthophotomosaics and point clouds through the application of SfM photogrammetry (**a** and **b**). (**c**) Examples of application: land use mapping and changes in topography

mosaic is obtained, and this is corrected geographically and geometrically, thanks to the spatial information provided in the preliminary steps. In this process, a colour correction is also performed in the boundary zones between photographs by homogenising the histograms of the adjacent pairs to obtain the final mosaic.

The application of SfM photogrammetry opens the door to a multitude of applications, both from the scientific and learning point of view. Once users are familiar with the software, orthophotomosaics can be obtained through a fast, automatic and easy, although blind, process. In general, better-quality products are obtained (e.g. lower georeferencing errors, orthorectified images) relative to standard methods of image georeferencing available in GIS. Point clouds offer a wide range of possibilities to characterise landforms and study changes in landscape properties and topography through time. This is important, especially from the point of view of historical analysis, since it allows the reconstruction of landscapes at various points in the past in both two (orthophotomosaics) and three (point clouds) dimensions; this means that we can look at landforms in a 4D dimensional way.

7.2.2 Image Classification: Land Use Mapping

7.2.2.1 Image Classification: General Explanation

Images are built as a mosaic of pixels or cells. A pixel represents the smallest area in a landscape that contains data. Images with large pixels provide less detail, while small pixels mean more detail is visible but require more computational time during image processing. The size of the pixels determines the spatial resolution of the image. For instance, an image with a pixel of 2 × 2 m indicates that the real area covered by the pixel is 4 m^2.

Images can have one band or multiple bands. One band means that each pixel is characterised by a single value. Multiple spectral bands, however, produce multiple values for each pixel, yielding more information for each one.

Digital image classification consists of the transformation of the values of each of the pixels into categorical values, based on some predetermined classification (Fig. 7.1).

But what exactly do the numerical values contained in a pixel represent? The spectral response captured in an image (in each pixel) depends on the sensor. Additionally, the type of sensor determines the number of bands the image can have. For instance, ordinary colour images have three bands, registering the response of the electromagnetic energy across three wavelength bands (red, green and blue (RGB)) in the visible spectrum. The combination of values for these three bands is what provides the colour we see the objects represented in pixels across an image. More complex sensors capture more bands, corresponding to different wavelengths along the electromagnetic spectrum. Therefore, the principle of image classification is one of using the different response of the bands to different objects to be able to identify them.

The definition of the categories used in the classification can be done in one of two ways, referred to as supervised and unsupervised classification. The supervised method implies a previous knowledge of the area and appropriate categories. The identification of samples (control points or polygons mainly) for each category is required. The software calculates the digital values in each category based on the sample values. Once the pixel values are segregated by category, differences between categories are computed (different statistical methods can be applied), and the rules that come from this computation allow each pixel to be assigned to a category. The unsupervised method uses automatic searches to find clusters of pixels with homogeneous values within the image; the user simply sets a total number of categories to be used. Thus, if, for example, the user is interested in identifying four landcover categories in the whole image, the software, based on the pixel values, finds the four groups can be best statistically differentiated. In this method, no prior knowledge of the study area is required, and the work of the user is more focused on the labelling and reclassification of the resulting groups than on providing input information to the clustering algorithm. See Chuvieco (2016) for full details of digital image classification procedures.

7.2.2.2 Image Classification: What for?

One of the most widespread applications of the digital classification of images is obtaining land uses maps (e.g. Foerster et al. 2014; Haliuc et al. 2018). Change and evolution of land uses and their causes (e.g. rural abandonment, forest fire) can be analysed and quantified based on multi-temporal land use maps. Likewise, image classification can be used to analyse other planimetric changes such as the evolution of the active channel width in fluvial systems (e.g. Batalla et al. 2018), glacier evolution (e.g. Marochov et al. 2020) or evolution of water masses (e.g. Torres-Batlló et al. 2020). The increasing frequency of satellite missions, along with the freely and easily downloadable data (downloaded from several official web servers; e.g. ESA-SENTINEL-2, European Space Agency) represents a great advance from the user accessibility point of view. Analysis is facilitated further by the availability of Open Source GIS (e.g. QGIS) to post-process and interrogate images, providing great opportunities for classroom learning.

7.2.3 Landscape Evolution: Changes in Topography

Three-dimension point clouds derived from SfM photogrammetry need to be post-processed in order to extract reliable spatial information. The first step is to filter the points by eliminating data that do not belong to the ground surface (e.g. buildings, vegetation), as well as other possible outliers that may create noise. The objective of this process is to obtain a model of the ground, representing the topographic elevation of the terrain, that allows comparison with other models of the same characteristics without the presence of other elements (such as vegetation) that may contribute uncertainty. The comparison between different point clouds is possible, thanks to the georeferencing process in the same reference system; however, residual misalignments can remain, and it therefore becomes essential to carry out a co-registration between the historical point cloud and reference point cloud by the pairing of stable areas (see Cucchiaro et al. 2020, for more details).

In order to analyse the spatial distribution of topographic changes and at the same time be able to obtain volumetric changes, filtered point clouds are transformed into continuous digital models in a raster format (i.e. digital image divided in pixels where each pixel represents the ground elevation). Therefore, interpolation is required to transform dense clouds into pixels representing Digital Elevation Models (DEM); i.e. each of the pixels of the raster file represents one value of terrain elevation. Landscape changes can be analysed if DEMs are obtained for different points in time (i.e. multi-temporal DEMs). A DEM of Difference (DoDs) is obtained from the comparison of DEMs from two different time periods (Fig. 7.1; e.g. Brasington et al. 2000; Lane et al. 2003; Williams 2012; Vericat et al. 2017). A DoD is a model representing changes in elevation (i.e. each pixel represents a positive or negative value, indicating elevation gain or loss). A DoD (a) provides the spatial distribution of elevation gain and loss that in a landscape, translated into maps of erosion and deposition, and (b) by the integration of these values through their area, allows computation of the volumes of materials eroded or deposited.

As mentioned above, in the case of archival aerial imagery, the overlap between photographs and the quality of the images may affect data accuracy and precision of the final products derived through SfM photogrammetry. The interaction of the magnitude of real changes in the landscape of interest and errors in the final products determines the limits of detection and the accuracy of this approach. If the magnitude of the changes is higher than the total error of the DoD, results will help in identifying zones of potential change, although absolute differences may be subjected to uncertainty. As long as these limitations are recognised, the method provides a way of obtaining spatial information from historical periods for which only archival aerial photographs are available and in turn provides a wide range of possibilities for the study of historical landscape changes. Several authors have recently used this approach to study topographical changes in fluvial geomorphology (e.g. Llena et al. 2020), mass-wasting processes (e.g. Leenman and Tunnicliffe 2018), glacial dynamics (e.g. Mertes et al. 2017; Midgley and Tonkin 2017) and coastal erosion dynamics (e.g. Carvalho et al. 2021).

7.3 Study Case: The Fiscal Catchment

7.3.1 Study Area

The Fiscal River catchment (16 km^2) is located in the middle part of the Ara River catchment (715 km^2) in the southern Pyrenees, NE Iberian Peninsula (Fig. 7.2). This is a mountain catchment with an altitude ranging between 749 m a.s.l. at the outlet and 1927 m a.s.l. in the headwaters. Like most mountain catchments in the Pyrenees, the Fiscal has suffered from anthropic disturbances that have affected its sedimentary dynamics, especially in the second half of the twentieth century due to major changes in land use (Beguería 2006; Garcia-Ruiz 2010). Other localized disturbances have also modified the transfer of water and sediments through Pyrenean catchments in general. For instance, gravel mining and channel embankments have a direct impact on river corridors, while the construction of large infrastructures such as roads or the extraction of sediments in open pit quarries modifies the topography of hillslopes; all of these change have a direct impact on sediment connectivity (e.g. Tague and Band 2001; Llena et al. 2019). The Fiscal catchment experienced a significant increase in forest cover and concomitant loss of meadow and bare surfaces during the second half of the twentieth century due to land abandonment (e.g. see (i) in Fig. 7.2). Furthermore, during the beginning of the twentieth century, a new road (5 km long and 20 m wide) was built crossing the river in the central part of the catchment (see (ii) in Fig. 7.2). Construction of this road induced important changes on the hillslopes and the movement of large amounts of material, modifying the natural drainage

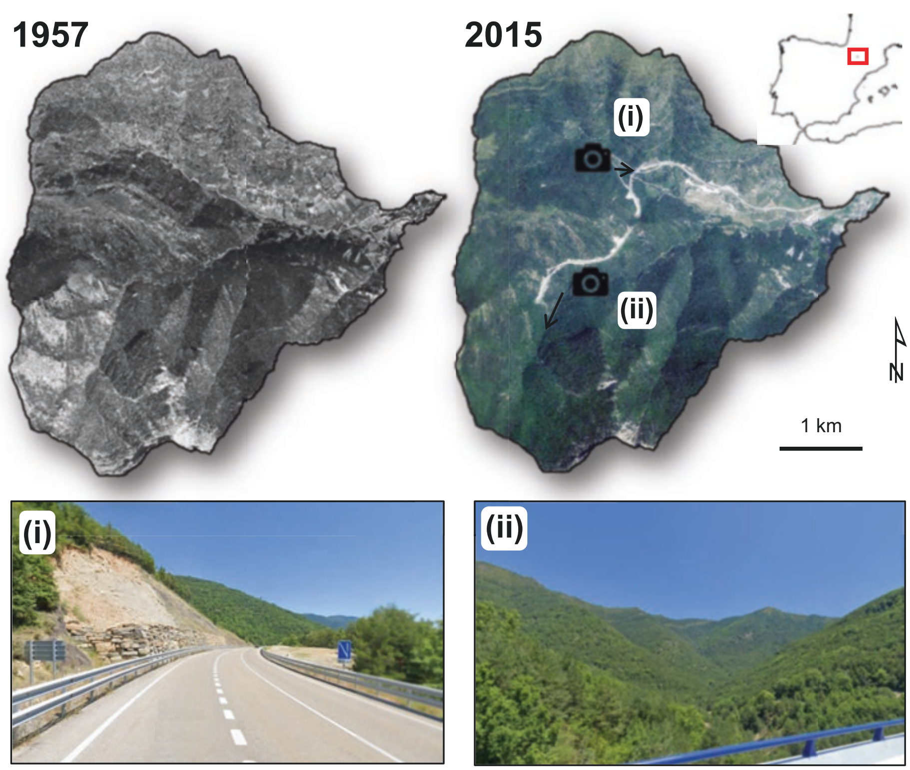

Fig. 7.2 Orthophotomosaics of the Fiscal catchment for 1957 and 2015. The red square in the Iberian Peninsula indicates the location of the catchment. (i) View of the road constructed in the central part of the catchment. (ii) View of a forested part of the catchment. Clear differences can be observed by comparing 1957 and 2015 conditions. The 1957 orthophotomosaic was obtained following the workflow presented in Fig. 7.1 and Sect. 7.2

network. All these changes make the Fiscal as an excellent case study for this chapter.

7.3.2 Objectives, Materials and Methods

7.3.2.1 Objective

The objective of this case study is the characterization of land use and terrain (topography) across the catchment in 2 years (1957 and 2015) in order to evaluate the impact of land abandonment and the construction of a road. Land abandonment has modified landcover in this catchment, while changes in topography resulted from road construction. The following text provides an overview of the datasets and analytical methods, with full details on how to apply these methods explained in detail in the supplementary materials section in the form of a tutorial; the supplementary material includes links to the datasets and the software.

7.3.2.2 Datasets: Archival Aerial Imagery

The 1957 dataset represents the landscape before the change or disturbance, while the 2015 dataset represents the landscape affected by the change. Each dataset consists of (a) an orthophotomosaic of 1 m resolution and (b) a DEM with a spatial resolution of 10 m. The methods followed to obtain these datasets were different for each year. In the case of 1957, the orthophotomosaic and the DEM were elaborated by the application of SfM photogrammetry to archival aerial imagery obtained from the Spanish National Centre of Geographic Information (CNIG) (see Sect. 7.2 and Fig. 7.1 for more details about the specific workflow). The 2015 dataset, however, consists of an orthophotomosaic and DEM provided by the Spanish National Centre of Geographic Information (CNIG). Both were obtained in the background of the National Aerial Orthophoto Program in Spain (PNOA) – the orthophotomosaic in 2015 and DEM in 2010.

7.3.2.3 Data Analysis

Land Use Changes

Land use maps were obtained through the application of an unsupervised image classification. The classification used the K-means clustering method, applied using QGIS 3.2. This determines the differences between classes in order to classify each pixel of the image as belonging to one of the classes. Orthophotomosaics were initially classified into ten classes (i.e. ten clusters in this method). Due to the limited spectral response of the 1957 panchromatic aerial photos, the ten classes were then grouped into three broader ones (bare earth, forest, meadow) based on photointerpretation. Classes were maintained for both years in order to be able to compare the land use maps. These classes permit analysis of the general evolution of land use, mainly dominated by afforestation. Once the classification had been carried out, it was possible to calculate the absolute and percentage area of each class for each year. These results provide insights into land use at two different points in time ('two snapshots', two maps) and the evolution of these uses over time ('comparing snapshots', one map showing changes).

Topographic Changes

Topographic changes were analysed by comparison of the 1957 and 2015 DEMs through a DEM of Difference (DoD), providing a gross estimate of the changes within the area affected by the construction of the road. A minimum level of detection (minLoD) was set in order to distinguish those cells in which the topographic change might be uncertain from those where the change is considered real (i.e. DoD > minLoD). This is a common practice in order to segregate the values of the DoD considered real from those that may be noise or uncertain change (e.g. Wheaton et al. 2010). The minLoD of a DoD can be assessed by propagation of the errors of each DEM being compared. This propagation can be computed in a 'simple' way (the root square of the sum of the square of the errors) or more sophisticated ways (see Wheaton et al. 2010 for more details). Anderson (2019) has recently presented an interesting discussion about the use of these minLoD for thresholding DoDs. In the Fiscal case study, a simple minLod of 2 m was applied, based on previously calculated errors (Llena et al. 2018). Therefore, those cells in which estimated changes are greater than 2 m (either in the positive or negative direction) are considered 'real', while changes less than 2 m (i.e. within the interval −2 to +2 m) are considered uncertain, potentially resulting from errors in the computation of the DEMs rather than being real topographic change. The DoD was calculated by the application of the GCD 7 software (Standalone), which allow change detection analyses and error thresholding. Results can be displayed in an Open Source GIS such as QGIS.

7.3.3 Main Results and Discussion

7.3.3.1 Land Use Changes

Land use maps of the Fiscal catchment showed a clear trend towards afforestation during the 58 years of the study period (Fig. 7.3). Forest cover increased from 57% of the total surface in 1957 to 68% in 2015. In contrast, bare surfaces suffered an important decrease, from 23% to 9% in 2015, while meadow increased slightly from 20% in 1957 to 23% in 2015. Afforestation mainly occurred on terraced slopes that were abandoned (see (i) and (ii) in Fig. 7.3) and in formerly active sedimentary areas that were stabilised by vegetation either in the upper parts of the catchment (i.e. erosional features, see (iii) and (iv) in Fig. 7.3) or in the valley bottom (i.e. the active floodplain, see (i) and (ii) in Fig. 7.3). Only areas

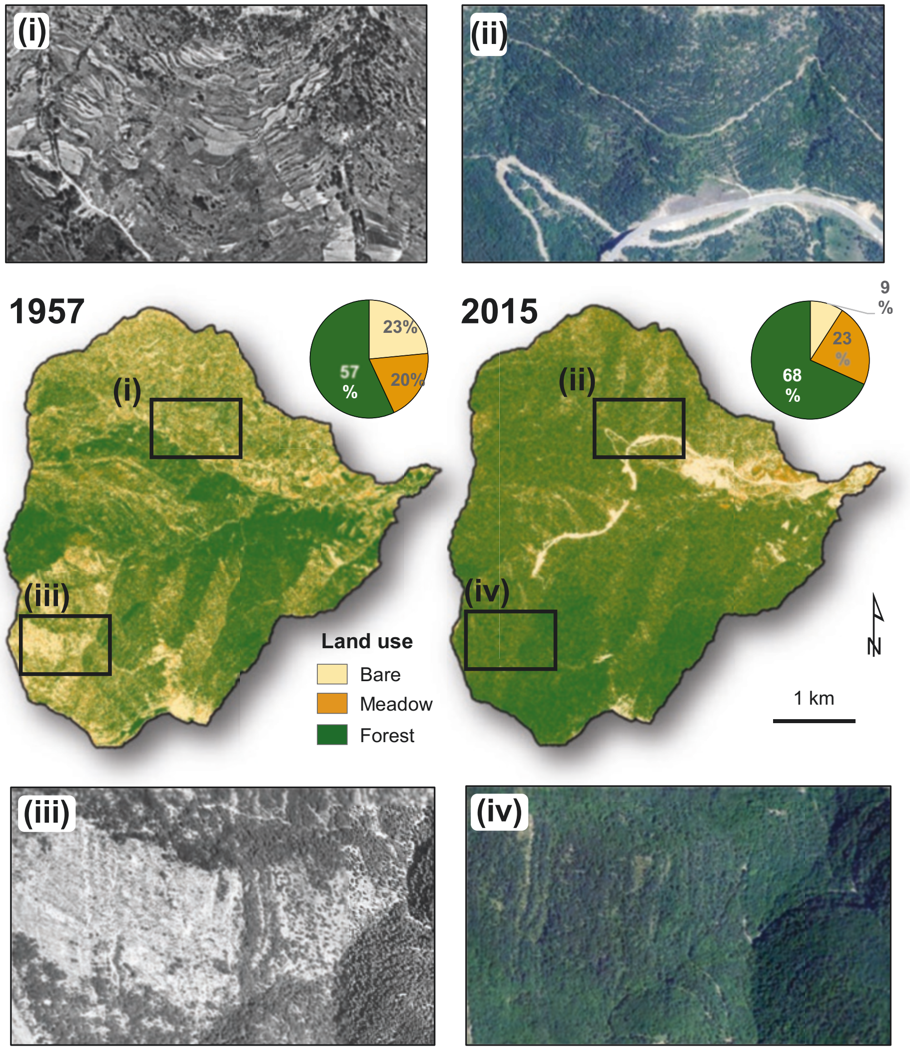

Fig. 7.3 Land use maps of the Fiscal catchment in 1957 and 2015. Pie charts represent the percentage of each land use (i.e. bare, meadow and forest). (i–iv) provide some examples of catchment areas that have suffered land use changes, as discussed in the text

directly affected by the road construction works experienced an increase in bare areas, with corresponding decrease in either forest or meadow.

The increase of forest during the second half of the twentieth century observed in the Fiscal catchment is representative of many Mediterranean mountain catchments. Several studies proved that afforestation is mainly driven by a combination of crop abandonment and decreasing grazing (e.g. García-Ruiz et al. 1996; Gallart and Llorens 2003; García-Ruiz and Lana-Renault 2011), along with climate change (e.g. López-Moreno et al. 2011; Macklin et al. 2012; Buendia et al. 2015; Zabalza-Martinez et al. 2019). The rapid increase of forest on abandoned terraced landscapes can be explained by the stability of these areas and their favourable soil properties. Terrace abandonment followed by strong scrub or meadow regeneration in humid areas improves soil quality and creates effective protection against soil erosion, ultimately favouring afforestation (e.g. Lana-Renault et al. 2014; Lizaga et al. 2019; Nadal-Romero et al. 2021).

7.3.3.2 Topographic Changes

The construction of the road involved engineering works with significant land movement along the routeway (Fig. 7.4). Since 'erosion' and 'sedimentation' resulting from the road construction were anthropogenic rather than the result of natural processes, we use the terms 'extraction' and 'deposition' respectively to represent the topographic changes in the Fiscal catchment. Mean depth of the sediment extracted as result of road construction during the period 1957–2015 was around −10.1 m, and the average depth of deposition was around 7.6 m. This yields a net change in elevation of −2.4 m. Twenty-one percent of the affected area by the works had values below the minLoD. Of the remaining area, sediment extraction dominated (70%), with deposition less important (30%). These respective changes were mainly due to the

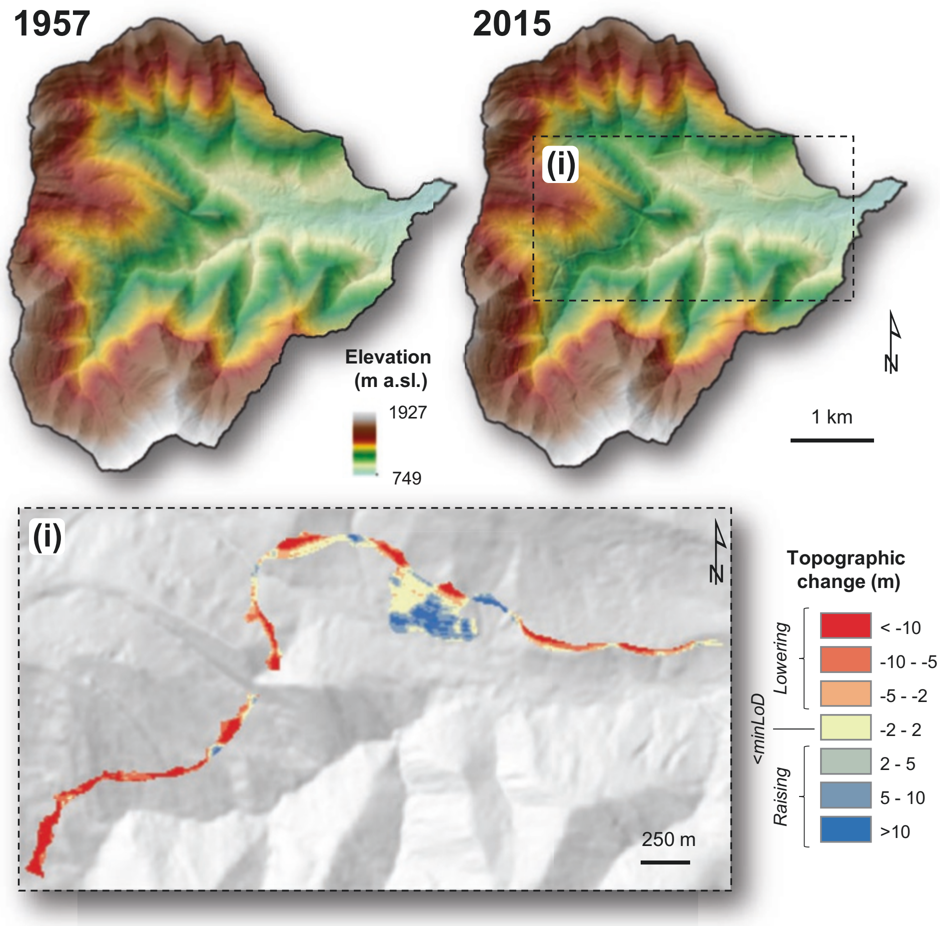

Fig. 7.4 Digital Elevation Models (DEM) of the Fiscal catchment in 1957 and 2015. The zoom-in (i) shows the associated DEM of Difference (DoD) representing the topographic changes

excavation of material from hillslopes and the infilling of depressions or deep channels (see (i) in Fig. 7.4). Analysis of the DoD shows that 1,457,277 m^3 of material was extracted from the area affected by the road construction during the execution of the works, while 637,543 m^3 of material was deposited. In terms of the total sediment budget, there was a net extraction of −819,734 m^3 of material. Net budget without taking into account the minLoD was −826,176 m^3, which only represented 1% of change.

Topographic changes caused by road construction influence the overall sediment transfer in two ways: (i) by inducing erosion downslope of the road and (ii) by capturing sediment coming from above the road and delivering it downstream. Due to the induced effects on flow paths and, consequently, on runoff, topographic changes due to roads may have a localised effect on connectivity (e.g. Wemple et al. 2001; Kalantari et al. 2017). The road artificially cut the drainage network, producing a localised increase in potential connectivity in the upslope area and a decrease in connectivity downslope. Therefore, the morphological variation due to road construction may lead to an increase of erosional processes uphill, triggering localised landslides in some instances (e.g. Persichillo et al. 2018; Llena et al. 2019).

7.4 Final Considerations, Conclusions and Tutorial

This chapter has provided a method for the post-processing of archival aerial imagery to allow the study of long-term landscape properties and dynamics, including both land use and topographic changes. It set out the basic workflow to estimate land use and topographic changes through the analysis of geographic information derived from the application of SfM photogrammetry to archival aerial photographs. The case study of the Fiscal catchment showed the insights that this workflow can produce. The supplementary material section provides a detailed tutorial based on this case study. The take-home messages of this chapter are as follows.

- The application of SfM photogrammetry to archival aerial imagery allows the extraction of orthophotomosaics and point clouds. Although orthophotomosaics can be directly analysed, point clouds require filtering and regularisation in order to compute Digital Elevation Models (DEM).
- Orthophotomosaics and DEMs can be analysed using GIS-based algorithms.
- A single orthophotomosaic or DEM allows landscape characterization (the study of its properties), while multi-temporal datasets allow study of the evolution and dynamics (landscape change).
- Digital image classification allows, among other applications, production of land use maps. From comparison of maps from different points in time, it is possible to analyse the evolution of uses, including both the spatial distribution of changes and quantitative changes in different land uses (the percentage change in each use).
- The comparison of DEMs permits analysis of topographic changes through time. As with land use, this includes analysis of the spatial distribution of changes and quantitative estimates of change expressed in terms of total gain and loss of elevation and corresponding volumes.
- The case study presented here shows that the Fiscal catchment has undergone afforestation processes during the period 1957–2015. The observed 11% increase in forest is mainly due to the abandonment of rural, mountain areas.
- The construction of a road in the central part of the catchment during the beginning of the twentieth century caused important local topographic changes, with these having potential effects on sediment transfer and connectivity.
- Application of the methods explained in this chapter allows the extraction of the geographic information needed for assessment of changes in the landscape through time and, in turn, assessment of their causes.

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8 The Internet of the Nineteenth Century: Railways and the Postal Service in France and Great Britain, 1830–1914

Robert M. Schwartz

Abstract

This essay provides an example of historical GIS and spatial statistics with a lab exercise and data that allow readers to apply these tools in practice. The data concern the emergence of the modern postal service in two European countries during the nineteenth century and the extent to which the growth of rail networks brought about daily mail across British and French territory. Using GIS with historical data on post offices and railway stations leads to spatial analysis of distances between any given post office and the nearest rail station. The results form geographical clusters of hot spots (very small distances) and cold spots (very large distances). In Great Britain and France, the aim and mission was to provide equitable daily mail service to all inhabitants. Hot-spot analysis over time shows the extent to which the desired benefits were realized.

Keywords

Postal service · Great Britain · France · H-GIS · Nineteenth to twentieth centuries

This essay provides an example of historical GIS and spatial statistics.[1] The subject is the emergence of modern postal services in Great Britain and France and, in particular, the development and spread of postal communication, mainly into rural and isolated areas of those countries. A current-day example is the effort to expand broad-band Internet to rural communities in the United States. Historically, the expanded nineteenth-century postal service functioned as the "Internet" of the era. Unlike the telegraph and telephone whose use at the time was limited to the wealthy—mail was a form of cheap, mass communication that made it possible for ordinary people on a regular basis to send and receive letters, postcards, bank drafts, and packages (especially at Christmas). Newspapers came by mail as well.

To get into the topic, consider how much you depend on rapid, mass communication today via the Internet? If it all suddenly stopped working, how would you feel? In the 1840s, people had different expectations about communications at a distance. If you were a student at a university, a letter from home was an infrequent though welcome event, just as a package from home provided a memorable moment. A shift in expectations took place as regular mail service was extended and deliveries were increasingly rapid. In rural England in the 1870s, for example, inhabitants in all but the most remote areas were becoming accustomed to the novelty of regular daily mail service, and interrupted deliveries were unwelcome. Sometimes weather events caused interruptions. In January, 1881, for example, a blizzard in Wiltshire County (western England) brought to a halt all postal deliveries. Newspaper accounts of the episode told how the interruption made people feel isolated and unsettled. Today, ask how you would feel if the Internet collapsed for several days.

One critical element in the story that follows was the partnership of national postal services and railways. Before the coming of rail transport, the mails were conveyed to designated towns by horse-drawn coaches. Communities outside of the privileged towns had to send out couriers to fetch the mail. The situation changed beginning in the 1840s. By then, the British government had harnessed the carriage and speed of steam-powered railways to expand postal service everywhere and especially to rural areas. To that end, railway companies were obliged to carry the mails to more and more

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cities, towns, and rural areas in accordance with the growth of the rail network and the opening of new post offices. The establishment of new post offices was to follow the principle of equitable service such that rural areas were to be favored in the allocation of new post offices; further, opening them near railway stations improved the speed and efficiency of postal service.

Using GIS with historical data on post offices and railway stations makes it possible to take up several questions. When, where, and to what extent does the historical geography of offices and stations indicate greater equity in postal service? If the majority of post offices in Britain were far from stations and rail transport in 1850, when and to what extent did newly opened post offices tend to be closer to new and existing stations? When and where were rural people likely to get daily mail?The method we'll use is to study evolving historical geography of extreme values, not averages but extreme values. The attribute of interest is the distance of a new post office from the nearest railway station. The reasoning goes like this. In the spatial distribution of new post offices in a given period, the greater the number of offices at great distance from rail transport, the greater the degree of geographical inequity in the system. More people in rural areas were getting slower mail service than others. Conversely, as the number of new offices at great distance declines, the degree of equity increases.

The spatial analysis technique that we'll use to study the evolution of inequitable/equitable service is Getis-Ord "hot-spot analysis." This is a means of identifying spatial clusters of statistically significant extreme values—both extremely low values and extremely high values. In our case, the values are the varied distances (kilometers) of newly opened post offices to the nearest railway station. Clusters of offices that were extremely close to stations are designated "cold spots." Clusters of offices extremely distant from stations are designated "hot spots." Comparing the patterns of hot and cold spot clusters at different times—1840, 1841–1860, 1861–1880, 1881–1900, and 1901–1914—makes it possible to study and describe changing degrees of inequitable and equitable postal service, i.e., mail by rail. When and to what extent did the government's aim of equitable postal service reach a point of success?

In epidemiology and medical topography, hot-spot analysis is often used to study the rates of cancer among populations in a given area. Hot spots indicate places where extremely high rates of cancer occur. Measures of statistical significance help us decide whether we can rule out chance as an explanation of high or low values. For example, if the probability score of high rates of cancer in a study area is 0.01, then we could say that rates that high could only occur by chance in 1 out of 100 cases. In other words, it is highly unlikely that rates that high could occur by chance. Confidence levels express the same idea in percentages. Cold spots with 99% confidence mean that they would only occur by chance in 1 out of 100 cases. Hence, we conclude these low rates are "real" and not the product of a chance process. Here is an example of hot-spot analysis in the geographic analysis of esophageal cancer in the United States.

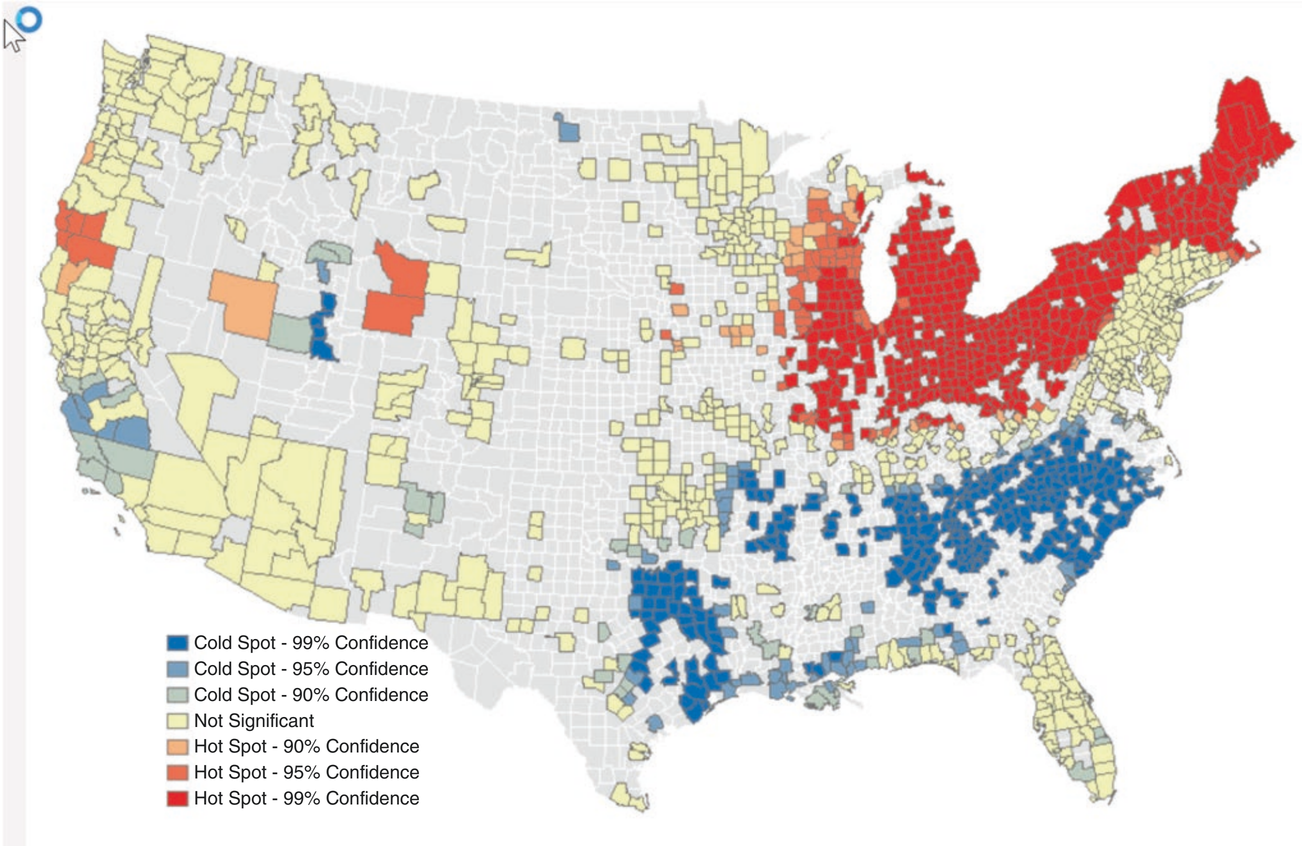
Hot spots are areas where the high rates (shades of red) and low rates (shades of blue) of esophageal cancer are each classified into three levels: 99%, 95%, and 90%. Rates that are statistically insignificant are labeled "not significant" and displayed in yellow below. The spatial units in this map are polygons designating health administrative areas. In your work with Post Offices, the spatial units will be points.

The following two maps show how cluster and hot-spot analysis is employed in medical typography to locate hot spots of esophageal cancer mortality and those for breast cancer among Caucasian women. Map 8.1 shows the spatial distribution of mortality, classified in levels of hot and cold spots. The Midwest and Northeast have significantly high deaths from esophageal cancer. The southern Atlantic states and the South show an exceptionally low rate of mortality.

Map 8.2 shows significant clusters of breast cancer incidence rates among Caucasian women per 100,000 persons at risk.*Turning now to nineteenth-century Europe*, central states there took up a new project: nation building. Prime examples were the unifications of Italy in 1861 and Germany in 1871. Once unified, the new states turned next to forging national identities and loyalties, aiming, for example, to assimilate Bavarians into Greater Germany. In this context, Britain and France evinced earlier varieties of the process. Already unified and possessed of national identities to varying degrees, both states instituted new policies to better incorporate their rural populations. A major tool in this effort was the postal service. Its expansion and reorganization, as viewed by administrators, would lead to greater political, cultural, and social integration. It would produce greater national cohesion. When people in remote villages and isolated farms could count on receiving daily mail, they were apt to feel a stronger tie to the national community. For the state, postal communications would yield increased knowledge of the population it governed and would therefore facilitate mobilizing political support and military force.

Putting these ideas to work is an interesting story, told here in three parts. The first concerns government policy. The second concerns getting the mail to and from home doors in town and country by postmen who delivered the mail on foot, walking designated routes. The third part examines the link between mail and rail.

The interworking of policy, postmen, and railways proved a transformative combination. The following tells the story by way of a comparative, spatial history.



Cluster analysis of mortality rates with esophageal cancer among white non-Hispanic men.

Map 8.1 Cluster analysis of mortality rates with esophageal cancer among white non-Hispanic men. (Source: https://labblog.uofmhealth.org/lab-report/higher-rates-of-esophageal-cancer-mortality-found-great-lakes-new-england, viewed September 21, 2021)

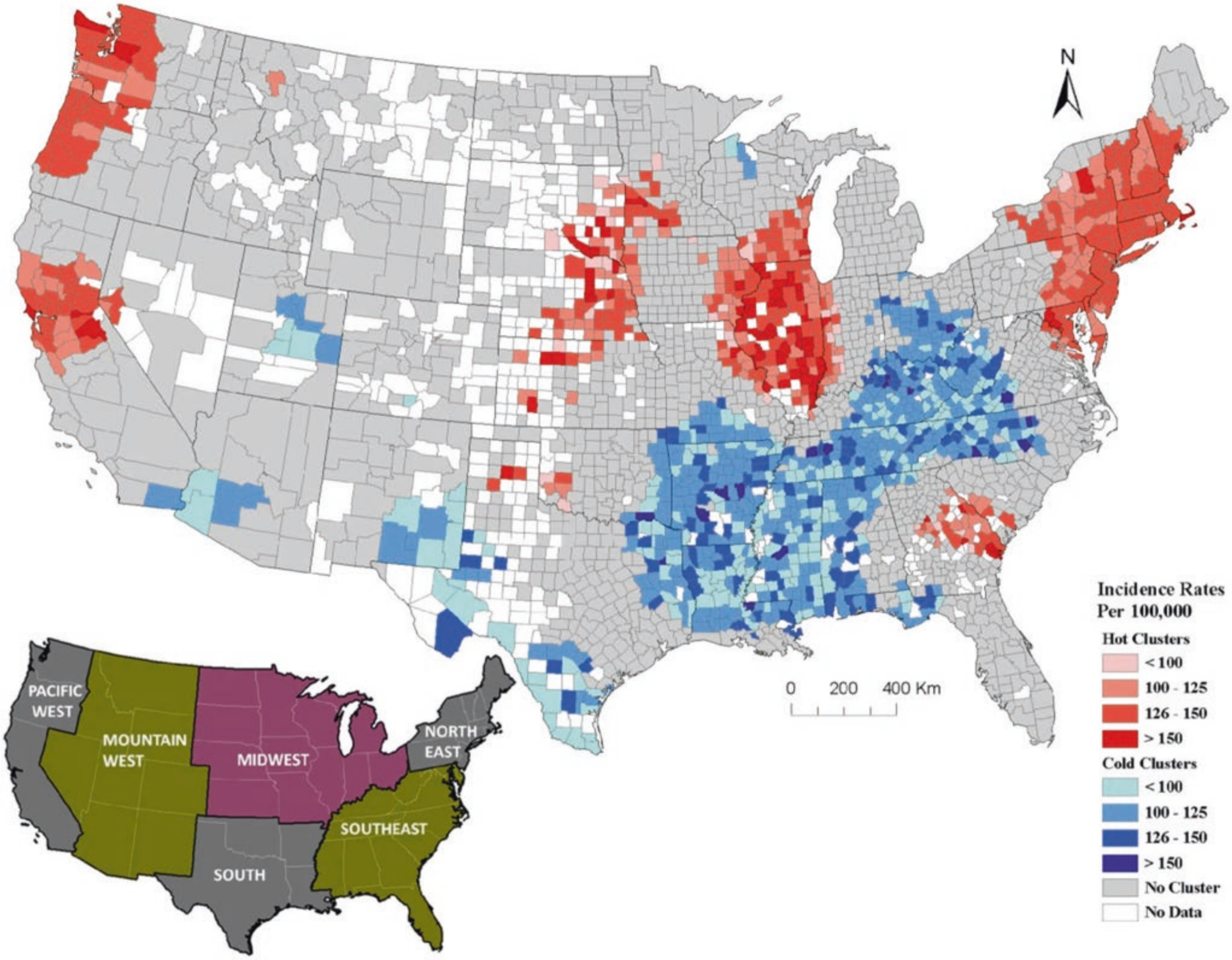
8.1 Engaging the Railways in France

In his report to the Minister of Finance in 1865, the Director of the Poste, Edouard Vandal, heralded a new component of La Poste, rail transport. The entire postal system, he wrote, relied on the *bureaux ambulants*, rail-borne traveling post offices that constituted "the main arteries of postal circulation" (Vandal 1865, 7). Every day, nine-tenths of some 1.8 million pieces of mail were conveyed. Organized in 1854, the system of "wagons-Poste" required the private rail companies of France to convey the mails on main rail lines. Contracts known as cahier de charges set forth the companies' obligations, which state administers were impowered to renegotiate from time to time.[2] In 1854, the contracts specified nine existing rail routes for postal conveyance and extended the obligation to lines opened in the future. At existing and future stations, companies were to provide office space for postal bureaus. At stations on secondary lines, they were to install letter boxes. Carriage of the mail was to be free of charge except when special requests called for additional trains (Recueil des lois 1875, 131–134) (Fig. 8.1).

The key steps of mail distribution were sorting, transfer, and delivery. During the railway voyage, employees in specially designed cars sorted the mail for offloading at the appropriate rail station. From a station, agents transferred the newly arrived mail to a main post office or to a branch office as needed, eventually to arrive in the hands of postmen who made the deliveries. As the rail network expanded, postal administrators were able to extend service to new localities with proximate rail transport. Thereby, directors thought, the gratitude of favored localities would grow.

In reality, several factors determined the creation of a new bureau. One was financial: the state expected the postal service not only to pay its own bills but to make a profit for the

[2] By design, the state granted rail companies exclusive privileges to carry freight and passengers in their designated and non-overlapping areas in exchange for state oversight.



Map 8.2 Geographical clusters of U.S. counties with significant high or low breast cancer incidence rates among Caucasians (including Hispanics) analyzed at a 200 km distance band. (Source: https://ij-healthgeographics.biomedcentral.com/track/pdf/10.1186/1476-072X-8-53.pdf, viewed September 22, 2021)

national treasury. A second factor was political: the prevailing view of "equity" among the governing elite and the conviction to put the idea into practice. Up to the 1870s, the principle of equitable distribution, set down in the law of 1829, was far from being realized. The situation changed under the Third Republic.

After the defeat by Prussia in 1871, reforming the Poste became a nationalizing project. In 1877, the Director of the Poste, Léon Rian, invoked the national project when he asked the Minister of Finance for additional funds. The functioning of postal service, he emphasized, was like a "sacred calling," for "it touches the most intimate interests of the population." The faithful and rapid transmission of correspondences was "a sacred trust" that requires "loyal personnel of integrity, energy, and experience" (Rian 1877, 8). The Poste, he continued, was a "civilizing agent, a carrier of enlightenment, a facilitator of commerce, industry, and science that strengthens familial bonds of all classes, thus serving as the best safeguard against demoralization" (ibid., 9). As it happened, he prevailed. Under his direction, more than 3000 bureaus were opened in new localities.

In 1900, Director Alexandre Millerand cited weakened national prestige to justify still further expansion. France "is far from occupying an honorable rank among the great

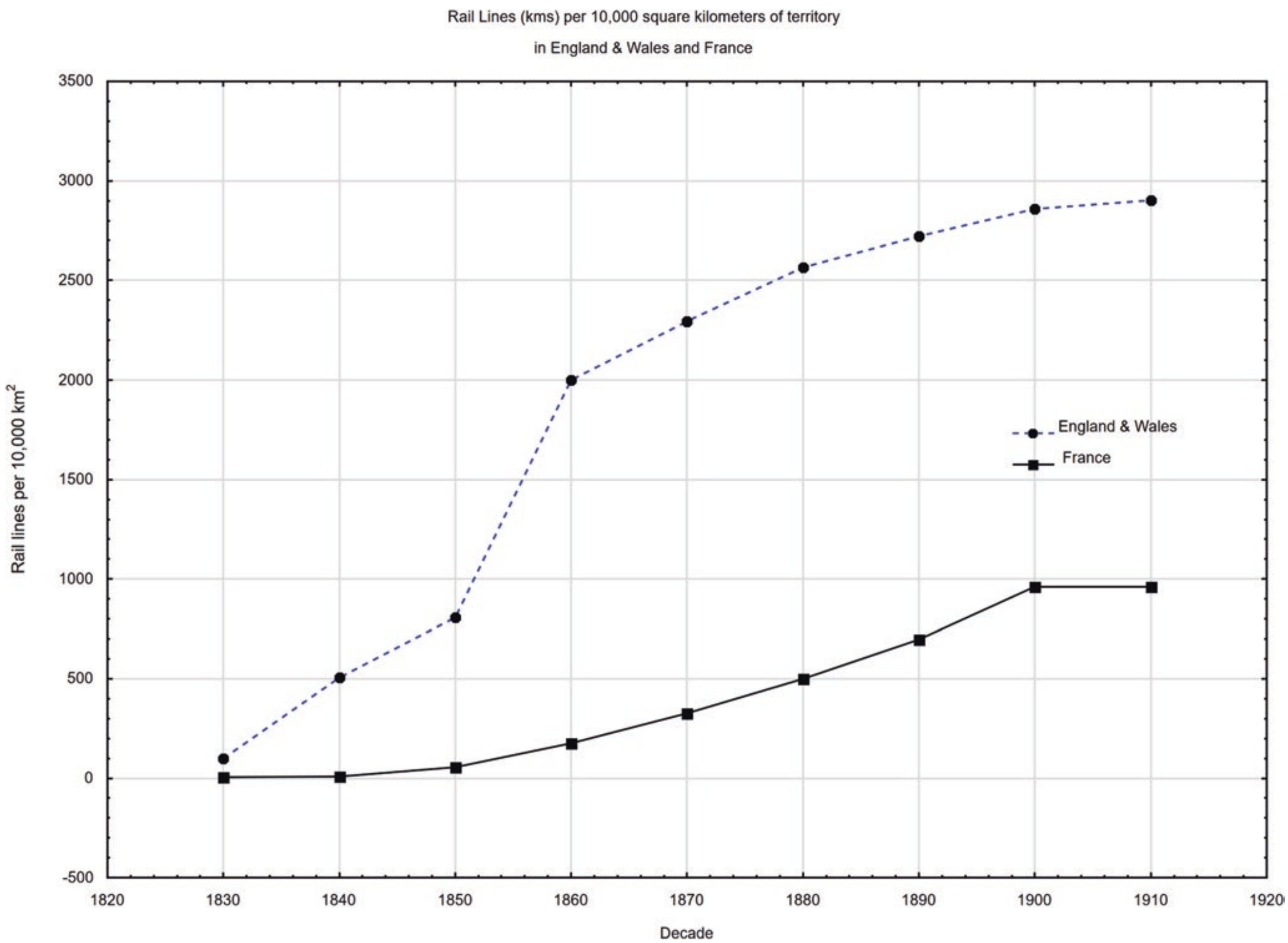


Fig. 8.1 The growth of rail service in Great Britain and France, 1830–1910. (Source: Data compiled by the author)

nations in terms of the number of postal establishments" (Ministère des postes 1900, 16). In 1897, Germany had 34,500 establishments; the United States, 71,000; and Great Britain, 21,200. Sadly, France had fewer than half [9, 458] the number of establishments existing in Britain (ibid., 166). Requests for new post offices, he continued, increase every day, as do the complaints when requests are refused. Of the 1200 received to date, 1000 of them are solidly based claims and were rightfully granted to communes more distant from a central office.

For Millerand, the traveling posts was one of the bright spots. Adding 49 new routes from Calais to Lille, Lyon to Marseille, and elsewhere, all from provincial city to provincial city, extended the arteries of circulation beyond those centered on Paris. One hundred postal trains, he added, were in daily operation, and the performance of the service was excellent. All told, the pairing of postal services and the railway yielded an annual movement across the network of 54,751,000 kilometers (ibid., 30). That flow could be improved if the critically overburdened system had new rolling stock and more personnel to relieve those working 12–15-h days.

8.2 Rail and Mail in France: Spatial Analysis

As the rail network extended across the country, so the railway arteries of postal service reached into hitherto unserved areas, and the volume of mail conveyed by wagons-poste continued to grow. In 1900, 70 trains each day conveyed the mails via wagons-poste, 35 leaving Paris for provincial centers and 35 moving from those centers to Paris (ibid., 40). From the 1870s, many new post offices were opened in or near rail stations, as indicated in Table 8.1 and Fig. 8.2, showing the related evolution of postal and railway capacities. As postal directors desired, major increases in the postal and rail networks clearly took place in the first decades of the Third Republic (1871–1941).

Table 8.1 Post offices and rail lines and stations in France, 1830–1913

	Post offices and the average distance in kilometers to the closest rail station				Railway lines and stations		
Year	Offices	Mean	Median	Std. dev.	Decade	Lines in km	Stations
1830	1429	63	56	41.5	1830s	222	61
1837	1433	63	55	41.9			
1843	1284	64	48	59.5	1840s	407	168
1853	1293	64	48.	59.2	1850s	3086	685
1864	1311	21	14	26.9	1860s	9776	1829
1873	5007	12	7	23.2	1870s	18,029	3270
					1880s	27,513	4991
					1890s	38,456	6983
1901	7930	2.9	1.1	40.1	1900s	53,083	8539
1913	11,619	3.3	1.5	41.1	1910s	53,083	10,219

Sources: Post office information from Nicolas Verdier; railway lines and stations from Thomas Thévenin and Robert Schwartz, Historical GIS of railways and stations in France, 1820–1930

The increasing dependence of the Poste on railways can best be seen as a geographical problem by mapping the proximity of new post offices to the nearest rail station in their respective areas. Chronologically, a proper point to begin is the decade of the 1850s when the partnership of mail and rail was formally established.

Here, we turn to spatial statistics to analyze the evolving pattern. In a given study area, the Getis-Ord Gi*statistic identifies spatial clusters of extreme values in a geographic distribution of an attribute. It then groups them into two categories of statistical significance: cold spots and hot spots. Clusters that are statistically insignificant comprise a group of values that are less extreme than those in the hot and cold clusters. Levels of statistical confidence refer to the probability that an extreme value would not occur merely by chance. In studies of the spatial distribution of cancer, hot spots indicate a cluster of places with exceptionally high rates of the disease, while cold spots are places with lower-than-expected rates. In the case at hand, the distance from a new post office to the nearest train station is the attribute of interest. Hot spots identify the offices that are outliers in the distribution because they are significantly farther from the nearest train station than all others in the distribution. Cold spots identify the inverse pattern: offices much closer to stations than all others. Comparing the patterns of extreme values over time (1853, 1873, 1901, and 1913) is a good way to gauge the relative accessibility of new post offices to rail transit in those years. A decline in the number and location of hot-spot clusters over the years will indicate degrees of improved accessibility and equity in postal service. An increase in hot-spot clusters will indicate a diminution of equitable service in the given year or period.

Figure 8.2 displays the results for 1853. Coming in an early phase of railway development, the hot-spot outliers (shades from dark gray to black) were extremely far from the closest station (not shown) in relation to the other values. This map will serve as the baseline from which to gauge changes in hot-spot clusters in following decades. For clarity, let us refer to hot-spot instances as "offices with distant links" to rail transit and cool spots as "offices with close links."

Two decades later in 1873, about 4000 post offices had been newly created, nearly a fourfold increase since 1853. (See Table 8.1.) By the 1870s, the railway network was also expanding rapidly, reaching much of the country, except the rugged terrain of mountainous regions in the south and the Alpine southwest. As one might suspect, the pattern displayed in Fig. 8.3 shows the concentration of new post offices very close to rail stations in Paris and its hinterlands (closely linked bureaus). Conversely, clusters of distant-link bureaus far from stations were, not surprisingly, predominant where railways had not reached in the southern uplands and mountainous areas.

In 1901, the transformation of the Poste in the Age of Rail was nearing completion. The distance of new post offices to rail transport, still geographically uneven, was much diminished throughout the country. (See Fig. 8.4 and Table 8.1.) Moreover, a few new bureaus were opened in mountainous areas. Figure 8.4 displays the pattern for the year 1901. Dense concentrations of proximate bureaus expanded in the Paris region and spread in the industrial northeast (Lille and Nancy) and in the urban center of Lyon. At the same time, numerous distant link outliers were scattered in regions lying below a line from Caen to Lyon. The interpretation of this deserves attention.

As the railways expanded and additional stations opened, the average distance separating a post office and the nearest station declined significantly, or in terms of accessibility, average accessibility of post offices to rail transport increased. The average distance to a station in 1901 was 2.9 kilometers, as compared to 12 in 1873. This was the difference between an easy walk and a half-day's trek. The shrinkage of postal space over the years entailed a change in the meaning of "close" and "distant." What was "close" in 1873 when the

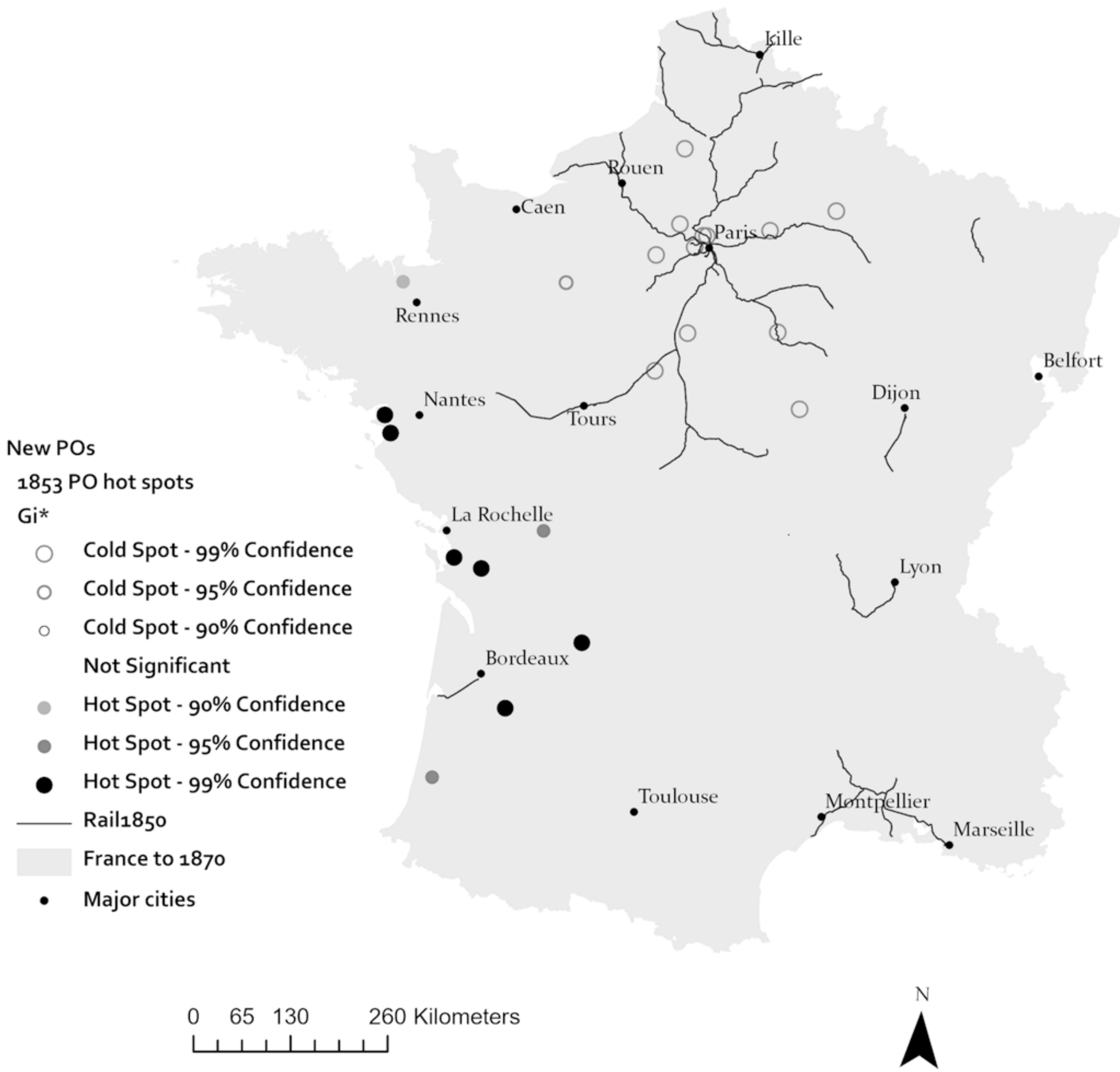


Fig. 8.2 Cluster analysis of newly established post offices in 1853

average distance was 12 km became "distant" in 1901 when the average had declined to 3 km. Returning to Fig. 8.4, the distribution of distant-link offices can be called the "geography of slower mail." All post offices would receive and dispatch mail, but it would take more time for offices at greater distance from mail trains to get the job done. The beneficiaries of the geography of faster mail were, of course, in the concentrations of closely linked bureaus and stations in Paris, the northeast, and Lyon.

Between 1901 and 1913, the creation of some 3600 additional bureaus attested to the government's concern to catch up with other European powers and advance the nation's international standing. In France itself, the effort proved a significant achievement. Of some 2793 cantons for which information is available, only 164 lacked its own post office. True, the geography of slower mail persisted in localities where new offices were opened, in the uplands and mountainous regions of the south and in scattered places around Dijon and in western Brittany. But that was only a part of the story. Indeed, the most interesting and consequential result was the development of a postal geography of equity. Long a national goal, greater equity in the placement of post offices arose from political will in policy and from the partnership of mail and rail (Fig. 8.5).

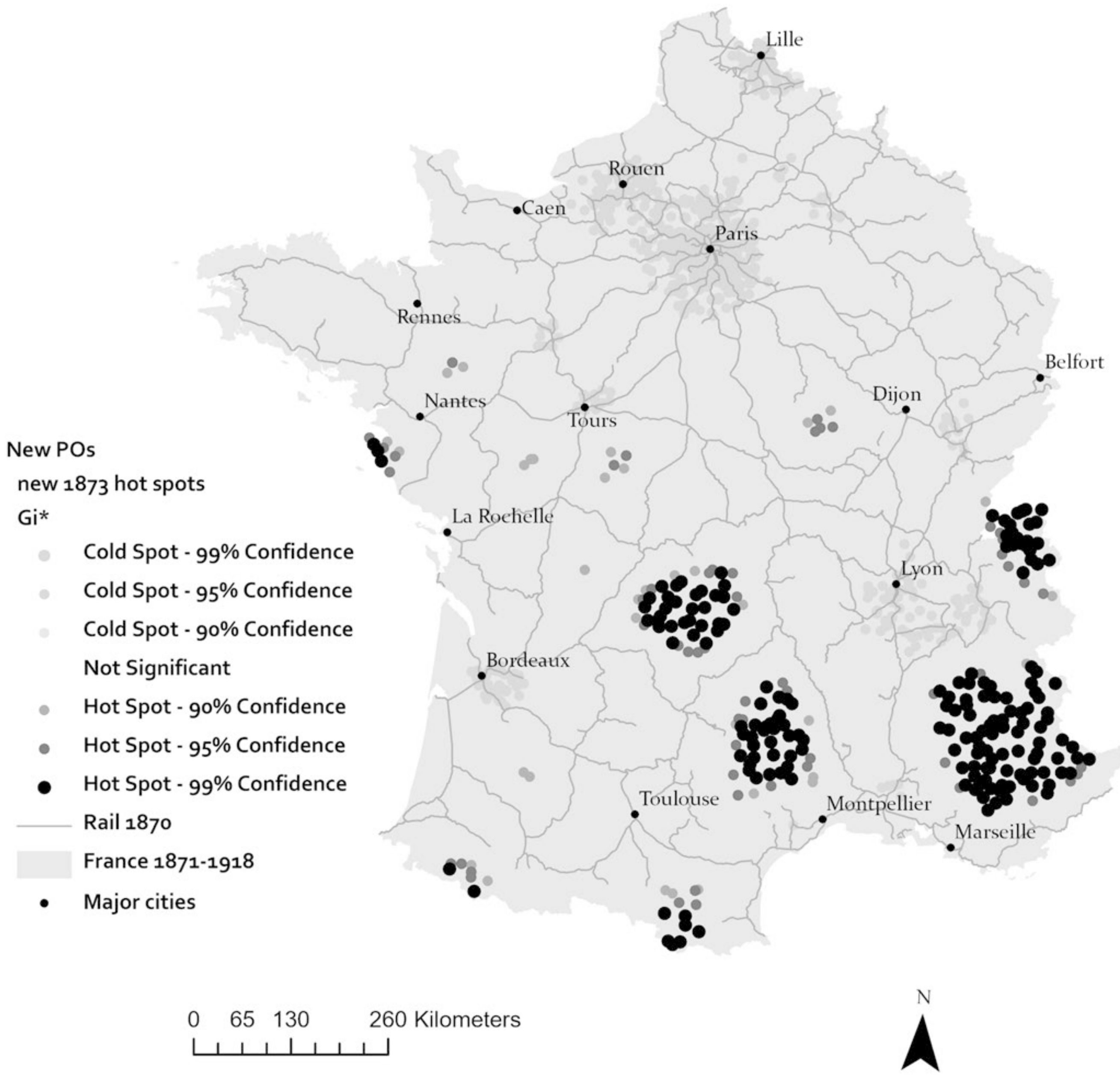


Fig. 8.3 Cluster Analysis of Newly Established Post Offices in 1873

8.3 Mail and Rail in Great Britain: Policy and Practice

In 1838, at the prompting of the Board of Trade, Parliament passed a law providing for the carriage of mail by railways, joining at the hip the post office and the first railway system in the world. According to the Board, the post office "was obliged to have recourse to railways, or suspend operation [because] the iron roads had already put a stop to most of the stage-coach traffic on principal roads" (Lewins 1865, 160). Two years later, in 1840, the Parliament authorized the post master general, Rowland Hill, to institute a low, uniform rate for mail postage throughout the country. Known as the Penny Post, a letter posted for 1 penny (pence) could be carried from London's Euston Station to Preston, Lancashire, in less than 11 h by train compared to 24 h by the fastest mail coach (Simmons 1991, 222). In 1846, the last London mail coach called it quits (Thrift 1990, 468). In the first 5 years of railway conveyance, the number of letters dispatched increased threefold, from 75 million in 1838–1839 to 219 million in 1842–1843. Daily mails from London on the major railway lines gave principal towns in the country two mails from the capital each day (Lewins 1865, 208).

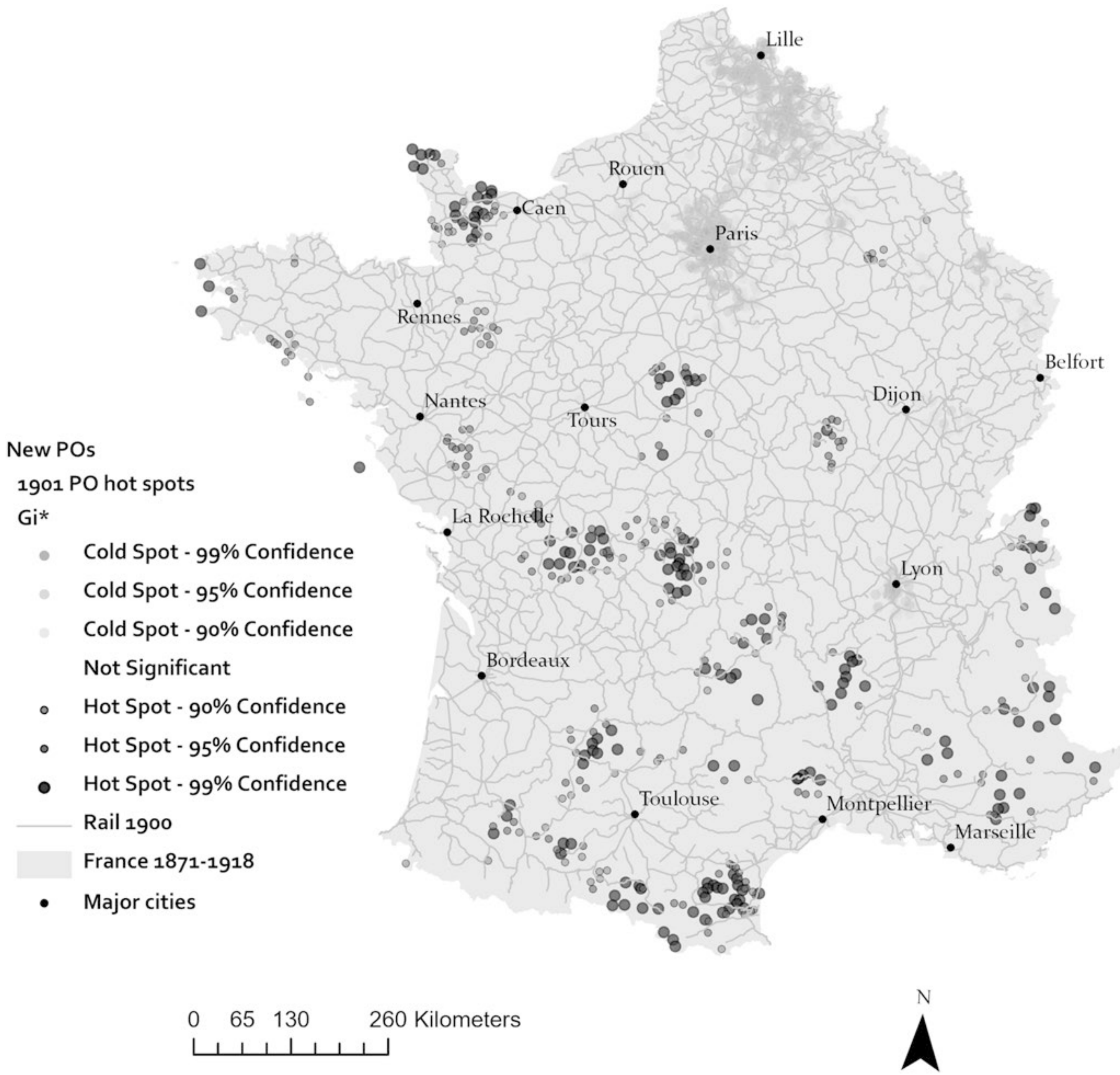


Fig. 8.4 Cluster analysis of newly established post offices in 1901

To extend postal service beyond the principal towns, the Lords of the Treasury issued a directive in August 1841. The expressed aim was the more equitable distribution of mail service than then existed. When considering the establishment of new post offices, areas where service was poor or did not yet exist were to be given priority over areas where a post office and adequate service already existed. Interestingly, the Lords rejected a policy in force in France at the time that was based solely on the ability to bear the cost of service. Setting cost aside, the Lords preferred treating postal service as a public utility. Every district, of which there were 630 in England and Wales, was to have at least one post office. A policy of equity was thus set forth at the beginning of the expansion.

The post master general managed the expansion. His first official report of 1854 was at pains to note that the increase in rural posts was gathering pace, with new or improved service introduced in 245 towns and villages (BPP 1855, 20–21). To serve areas where the volume of correspondence was insufficient to warrant a new office, a new corps of rural messengers was created, composed of carriers "who in a walk, including generally small villages, afford the inhabitants frequent and regular opportunities of sending and receiving letters" (ibid., 20).

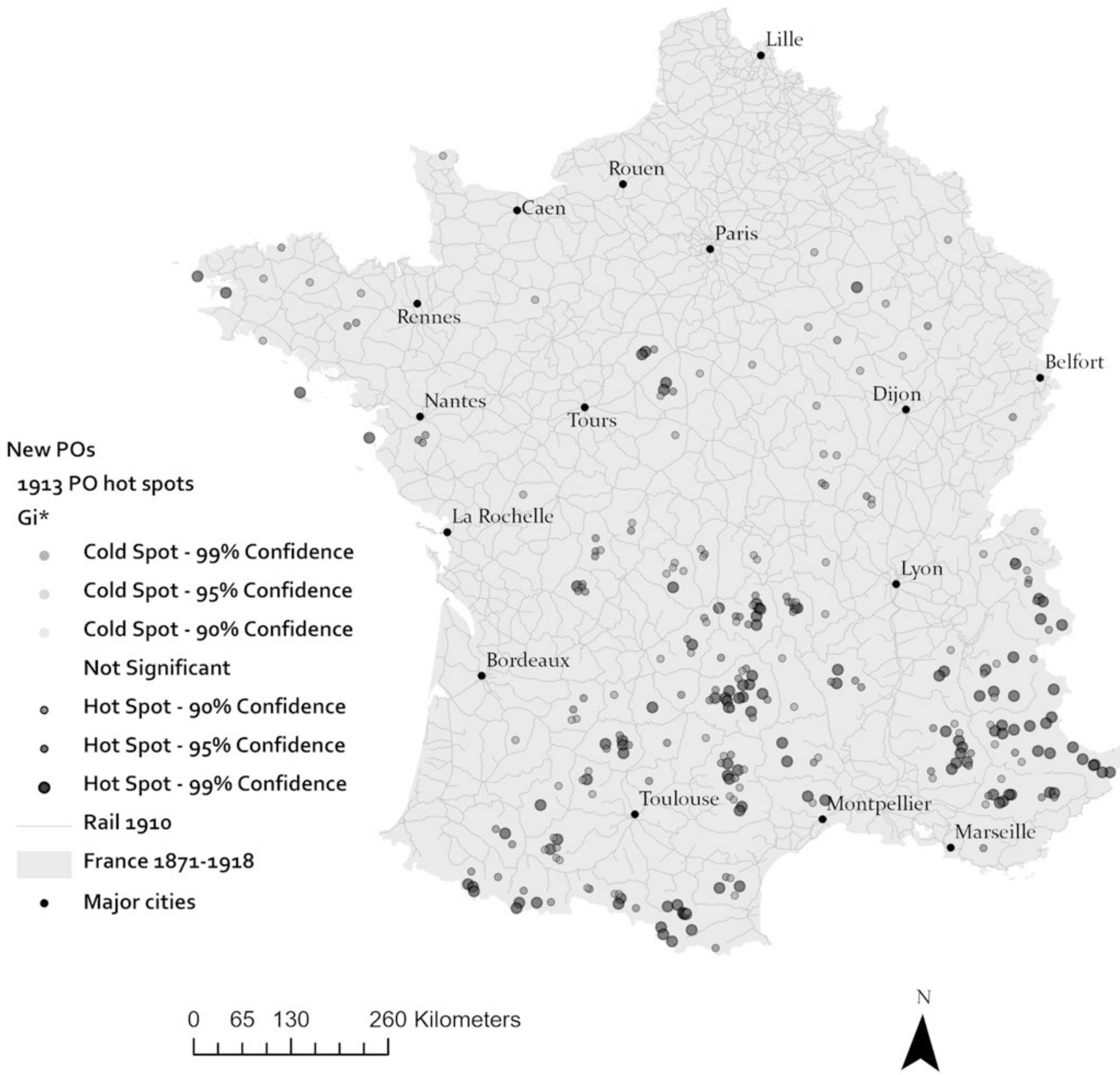


Fig. 8.5 Cluster analysis of newly established post offices in 1913

Gradually and unevenly, postal service to rural and remote areas advanced. At the turn of the century (1898), the post master general underscored the progress: "One of the most important features of the postal history of the year under review is the extension of the rural deliveries" (Post Office 1898, 7). Universal delivery, he admitted, would require more time, and remote homes might not get daily delivery soon, but the goal, he emphasized, was now within sight.

Table 8.2 captures a major component of the progress, the growth in the number of new post offices and the simultaneous expansion of railways and rail stations. The tallies of new post offices and periodic totals show that the greatest expansion took place in the first two decades of the project. A second expansion in the decades of 1880–1900 underpinned the claim in 1898 that universal delivery was on the near horizon. In 1914, the post master general reported that the goal had been reached (Post Office 1914, 24).

Table 8.2 Growth and proximity of new post offices to rail stations, England and Wales, 1840–1914

		Post offices opened and average distance in kilometers to closest station		Stations opened		Rail lines open	
Period	Count	Cumulative	Mean distance	Mean distance	Count	Cumulative total	Kilometers
To 1840	2208	2208	49.92	42.70	340	340	7668 (1840)
1840–1860	4682	6890	6.15	4.65	1985	2325	21,119 (1860)
1860–1880	1563	8453	3.67	2.81	1985	4310	30,250 (1870) 34,690 (1880)
1880–1900	2825	11,278	3.12	2.69	1092	5402	38,773 (1890) 41,143 (1900)
1900–1914 All POs in 1914	1466	14,536	2.7	2.2	788	6190	43,187 (1910)

Sources: Ken Smith and Nick Bridgwater, annotated lists of UK post offices (https://sites.google.com/site/ukpostofficesbycounty/home). POs opened at unknown dates are omitted. I compiled the figures on rail lines and stations through my work with Historical GIS of British Railways, constructed under the direction of Jordi-Martí Henneberg

8.4 Mail and Rail: Spatial Analysis of Britain

Table 8.2 also shows how the proximity of new offices to the nearest station increased substantially from 1840 to 1914. Where and when were these offices established? Here, temporal geography yields the answer by studying the evolving geographic relationship between the location of newly created post offices and their proximity to stations in the growing railway network.

Figure 8.6 maps the spatial distribution of new post offices in five periods—1840, 1841–1860, 1861–1880, 1881–1900, and 1901–1914. The first period of expansion from 1841 to 1860 proved the most geographically extensive, followed by that from 1881 to 1900. At the same time, the rail network of lines and stations grew substantially after 1840. By 1900, rail lines totaled 41,000 kilometers, double the total in 1860 and more than a third larger than the total in 1870. (Maps of railways are omitted to meet the constraints of article length.)

For the pre-railway period up to 1840, the number and location of post offices were evidently determined largely by population density and proximity to ports and major cities. Thereafter, the policy of favoring sparsely populated districts for new bureaus took hold, while the factor of high population density steadily weakened as did the favoring of large towns. As in France, it seems a trend toward greater *geographical* equity was developing in Britain. To test this hunch, the same method used for France—Getis-Ord cluster analysis—works well. Figure 8.7 maps the distribution of the distance from existing post offices to the nearest railway station in 1840. The map depicts the distribution of two types of linkage: close links (cold spots) that characterize offices very near stations and distant links (hot spots), offices very far from stations. Close link clusters populate the corridor comprising the industrializing North and Midlands, greater London, and the southern counties of Hampshire, Surrey, and Kent. Offices with distant links were clustered in East Anglia, the Southwest, and Wales. Equitable coverage of mail by rail had yet to make any headway in these peripheral regions of the country.

Forty years later, the geography of mail by rail had changed markedly. Figure 8.8 displays the evolution toward equity in placing new offices, showing the diminished presence of weak-link outliers in smaller clusters of districts in Wales, Norfolk (East Anglia), the West and Southwest, and agrarian areas of the far North.

Compared to 1840, clusters of close-linked offices were tightly concentrated in and around London, in the manufacturing districts in the Midlands and the North, and in the coal fields of Newcastle and southern Wales. This pattern for the period 1861–1880 (Fig. 8.8) represents a midpoint in the evolution of postal access.

From the 1880s to the eve of the Great War, the geography of developing equity in the postal network neared completion. During the first two decades (1881–1900), the post master general had large numbers (2825) of new offices opened in small towns and rural districts in areas previously neglected: in East Anglia, in a band of communities between Birmingham and London, in the Southwest, and in Wales. (See Table 8.2 and Fig. 8.9.) This reflected the postal administration's effort to carry out the expressed priority of extending service to underserved districts. The large increase in new offices greatly outpaced the growth of rail stations. With the average distance to new stations being small (3.1 km), many new offices were located beyond the average proximity and are indicated on the map as outliers with distant links. (See Fig. 8.10 and the distribution of insignificant office locations.)

Fig. 8.6 The expansion of post offices in England and Wales, 1840–1900

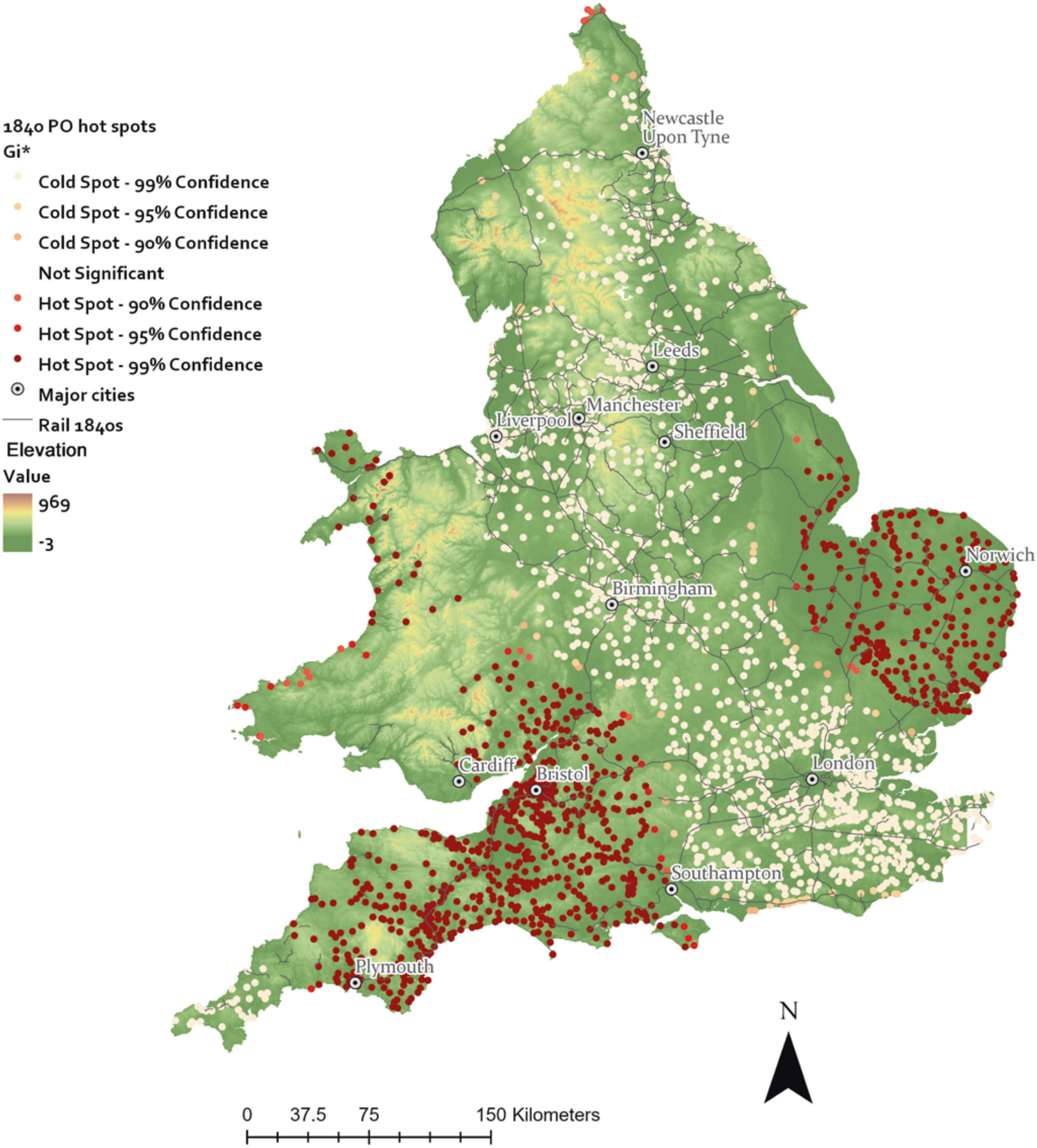


Fig. 8.7 Cluster analysis of post offices open in 1840 and their distances to the nearest railway station

During the period 1901–1914, the desired goal of equity in the placement of new offices in the postal network was more or less realized. Of the offices opened (1466), those with distant links to rail transport were few in number and widely scattered. Few also were the districts with clusters of outlier offices. All in all, the network in 1914 was made up of 14,536 post offices. The average distance to rail transport was less than 3 km (2.6). In seven out of every ten cases, a walking postman could carry mail at his post office to the train station in less than an hour. A horse-drawn van would arrive sooner. Geographically, the partnership of mail and rail made everyday delivery the norm in all but a relatively few rural communities.

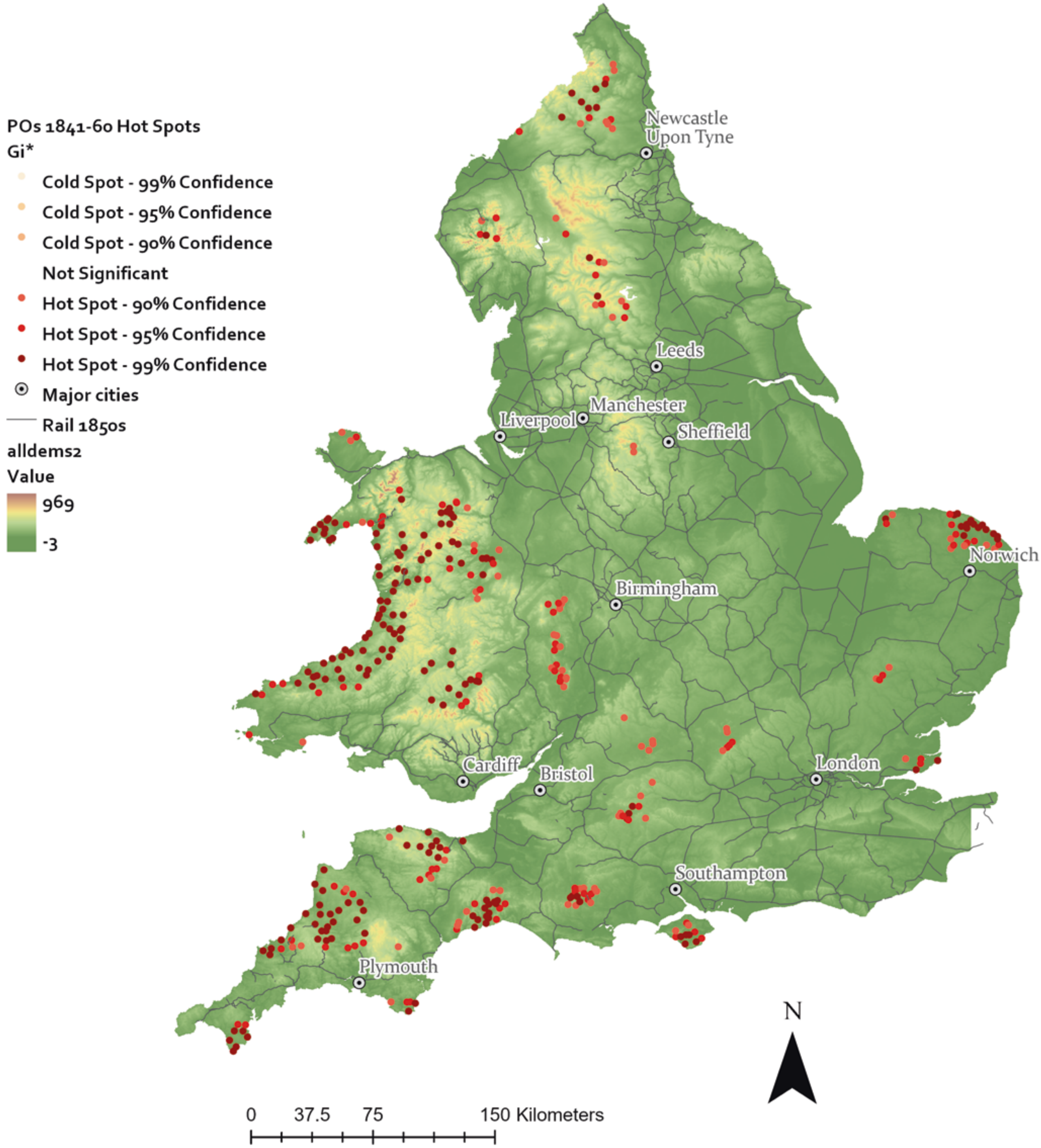


Fig. 8.8 Cluster analysis of post offices open in 1841–1860 and their distances to the nearest railway station

8.5 Conclusion: Convergence and Difference

Regular postal communication brought state services to homes in rural communities and remote farmsteads, earned the gratitude of residents thereby, and likely strengthened local sentiments of belonging to the nation. Beginning in 1830, France moved first to get the daily mail to all rural homes using the legwork of thousands of postmen walking designated routes. Both states embraced the principle of equity in postal service, so even remote and isolated households would be incorporated into the national postal system.

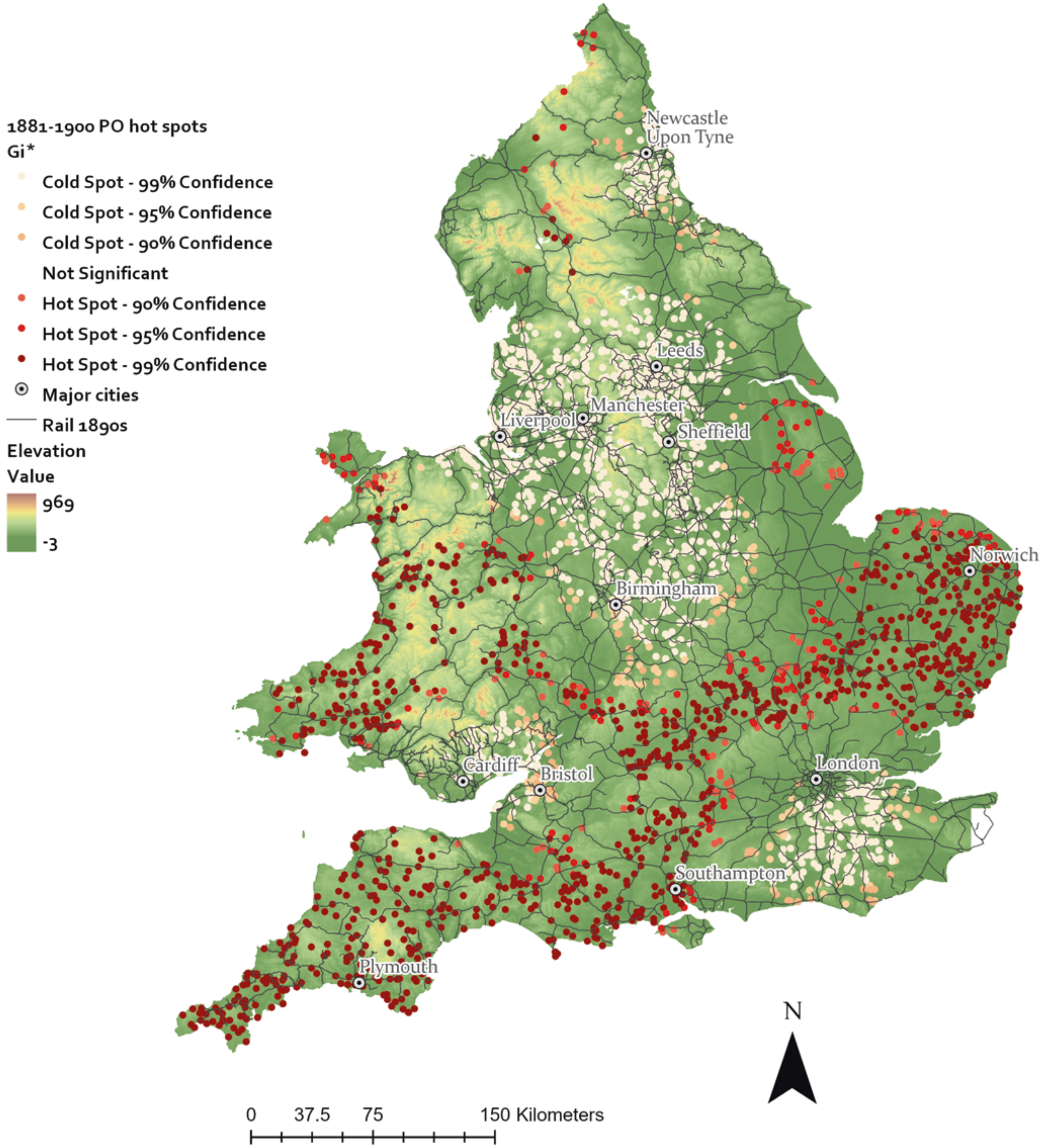


Fig. 8.9 Cluster analysis of post offices open in 1881–1900 and their distances to the nearest railway station

The partnership of mail and rail fostered the application of principle in practice. In 1838, Britain, followed by France in 1858, combined state postal services with the growing railway networks of private companies. Although the plan for universal daily mail in France and Great Britain remained partially incomplete on the eve of the Great War (1914–1918), incremental steps toward the goal had been made. The emerging geography of equity in the establishment of new post offices proves the point.

Differences in scale, terrain, and timing deserve mention as well. The singular differences for France were numerous: the much greater size of French territory, the comparatively

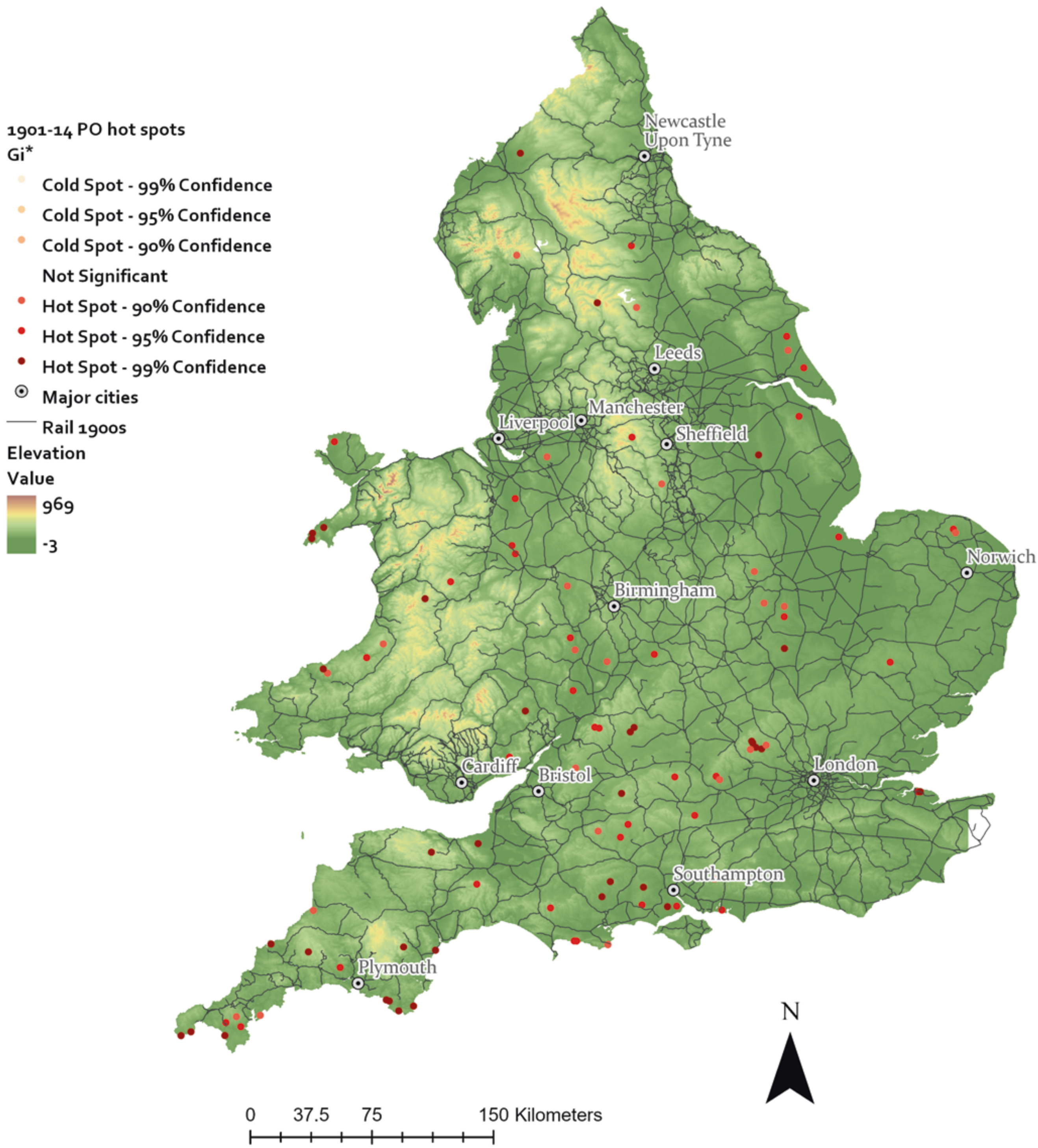


Fig. 8.10 Cluster analysis of post offices open in 1901–1914 and their distances to the nearest railway station

vast size of its rural population, its extensive mountainous regions, the later and gradual development of railways and an industrial economy, and the obligation of the Poste to generate a surplus for the state treasury. These characteristics shaped and delayed the modernization of the French Poste. The defeat by Prussia in 1871 and growing international rivalries fortified the republican political will to further postal expansion, defining it as a nation-building project.

Unlike France, the British state was the supranational organization that ruled over the multinational territories of the British Isles—England, Wales, Scotland, and Ireland. In 1707, the state combined these territories into the United Kingdom. England had always been the dominant country and the predominant power in the British state. As "Britain," England and Wales were governed essentially as a single polity with uniformity in law and administration. Wars and imperialism gave rise to a British identity in a shared response to external events and foreign foes. (See McCrone 1997; Langlands 1999.)

Arguably, the British program of postal reform and expansion was domestic nation-building. The mission inherent in modernizing postal communication was political and cultural integration. In this, Britain enjoyed advantages over France. The most important ones were its lead in industrialization, its territorial compactness, the greater density of its rail service, and the fact that the majority of its total population were urban dwellers by mid-century. In contrast to France, the governing authorities strongly held the conviction that the postal service, especially in the countryside, should be a public utility, not a profit-making resource for the treasury. For these reasons, the British partnership of mail and rail matured earlier than that for France.

Overall, the results of postal modernization in both France and Great Britain converged.

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9 The Historical Relationship Between the Railway and the City

Luis Santos Ganges and Jordi Martí-Henneberg

Abstract

This chapter will study the complex, and changing, relationship between the railway and the city throughout the course of modern history, analysing it from an urban perspective. This is a specific theme within the wider field of urban expansion and one that needs to be considered. Our scope will be that of studying the spatial impact of the railway in the city. To do this, we will focus on two of these impacts, which are very different in nature: those exerted by railway stations and those caused by railway lines. We will present case studies of Spain, the Netherlands and Romania.

Keywords
Railway station · City · H-GIS · Nineteenth-twentieth centuries

This chapter will study the complex, and changing, relationship between the railway and the city throughout the course of modern history, analysing it from an urban perspective. This is a specific theme within the wider field of urban expansion and one that needs to be considered alongside Chaps. 3 and 10, about railways, and Chaps. 2 and 12, on urbanisation. Our scope will be that of studying the spatial impact of the railway in the city. To do this, we will focus on two of these impacts, which are very different in nature: those exerted by railway stations and those caused by railway lines.

Firstly, urban stations have given rise to different phenomena in their immediate surroundings. To interpret these, it is a good idea to differentiate between the building that serves passengers and the rest of the associated facilities that make up a railway station: those for handling goods and which house technical elements. On the one hand, the passenger building is the most representative and iconic element of the railway service and of the company that manages it. With more, or fewer, metal signs and monumental architecture, passenger buildings have always presented themselves as new urban focuses of attraction. This has been especially true of the bourgeois city: which materialised in the form of new areas of urban expansion and generators of a new urban centrality. On the other hand, the facilities for goods and technical services (warehouses and workshops), although very important, have had less attractive urban impacts, as they have mainly been spaces for the movement of goods wagons, logistics and storage. As far as the deposits have been concerned, these have been dedicated to the maintenance of locomotives, while the general workshops have been the industrial spaces associated with the railway. All of these facilities have generated employment, and especially the workshops and warehouses. In addition, they have welcomed houses related to moving trains and production and have therefore largely been associated with noise, smoke, soot and working class labour, which has determined the zoning of urban expansion (in Fig. 9.1 the southern part of the tracks in Valladolid).

One theme which is central to this chapter about the relationship between the railway and the city is the dichotomy between the station as a focus of expansion and the railway lines as an urban boundary. As a result, to interpret the influence of the railway on centrality, it is necessary to distinguish between the attraction of the main building to travellers, as opposed to the repulsion caused by the rest of the installations. It will also be necessary to take into account the fact

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Fig. 9.1 Valladolid

that there were other pieces of transport infrastructure that played a central role in urban transformation, such as sea and river ports and the main roads (Chaps. 4 and 5). We have divided this text into six sections: the travellers' building as a focus of centrality; the industrial space of the station and of workers' neighbourhoods; the railway line as a limit or a barrier; the railway crossings; the railway and spatial segregation; and the use of GIS in studies of the station and the city. We shall give particular attention to the cases of cities in the Netherlands and Romania, as those referring to Spain will already have been used in subsequent sections.

9.1 The Passenger Building as a Focus of Attraction for Urban Expansion and as the Generator of a New Centrality

Every station is a break of bulk point and a transhipment unit that must attend to the complementarity between the things that are moved by the railway and by the city. The station is a stopping point for trains and a space equipped with tracks, facilities and buildings. As a whole, it serves the double function of providing services to its users and ensuring the functioning of the railway. The station is, therefore, a multi-functional setting, in terms of railway logistics.

Since its inception, the term station has brought together a series of elements that are not only diverse but also ultimately incompatible with each other and which have conflicting impacts on the urban fabric. On the one hand, there is the main building for travellers. On the other, there are the services that the company provides relating to merchandise and to functional needs, such as the circulation of trains and the maintenance of the material. The initial station model was mixed and encompassed all of these functions. However, later, passenger stations were built, and such stations specialised in passengers, merchandise, the classification of wagons and merchant trains and even technical stations that did not serve the public. These facilities met the functional and logistic needs of the companies, and their location had a considerable influence upon the city.

In all cases, the station that is open to the public is a relevant place within the city in urbanistic terms. Due to its role in attracting travellers, it must appear open. It is a focal point of exchange which, while belonging to the railway system, interacts with the city. This is where the idea of the station as a *gateway*, proposed by Raymond Unwin, back in 1909, came from and its urban surrounds, which should be treated as a modern *entrance gate* to the city:

> We have seen that one focal point of traffic is likely to be at or near the railway station, and that in the modern town the railway station at which the majority of people will arrive and from which they will depart seems to demand much the same empha-

> sis that was given to the ancient town gateways (…) in front of the station there should be an open space or place to give dignity to this main entrance to the town and to afford space for the bustling traffic which must congregate there. (Unwin 1909: 187)

Before the emergence of road traffic, at least during the first century of its existence, the railway station represented the speed and comfort of communications, access to the national market and the strength of capital. For this reason, as well as being a dispenser of what were – from a social perspective – highly valued services, its passenger building was also often an architectural icon of the company's prestige. All of this led to the station becoming a new pole of attraction within the context of the nineteenth century city that was in a process of transformation. In general, the main stations achieved symbolic value, as they were projected and constructed as *representative buildings* and behaved as *urban landmarks* within the urban space. They even became an *urban focus*, as places of reference within the city, and also *urban nodes*, as they were built as strategic points of connectivity (Santos, 2023).

Urban planning practice understood that the railway station should be the focal point of urban expansion (Santos y Ganges 2007 and Purcar 2009). This explains why it was so common to build a public square in front of the passenger patio (the *cour de gare*, *Bahnhofsvorplatz*, *station square*, *plaza de la estación*), which favoured its function as an urban focus of the node (Biddle 1986: 37). In earlier studies – which we will detail later – it has been shown that, in general, the growth of the city was directed towards the passenger building of the railway station (Álvarez-Palau et al. 2016), which meant that it became a functional focus. This will be the subject of the exercises in the tutorial. Urban planning incorporated this effect related to the attraction of centrality and particularly in cases in which the station was located at such a distance that it required the preparation of new building and road space to connect it to the city. In this sense, it is relevant to distinguish between stations on passing lines (through stations) and end-of-line stations. Passing lines were built approaching the city but always leaving a certain distance in order to seek low-cost expropriations, and connection to the city will follow (Fig. 9.2). End-of-line stations, on the other hand, could come closer to the city or even enter it.

For practical reasons of cost, both through stations and end-of-line stations were mainly located outside the city, where there was land available. Although this was not habitual, there are examples of the penetration of end-of-line stations into the old city, above all, at ports (Calais, Gijón, Hamburg, Southampton, Stettin and Trieste), as it was of fundamental importance for the train to interconnect with maritime transport. However, this also occurred at passenger-only terminals (Amsterdam, Antwerp, Brussels, Lille and Lisbon) and at mixed stations (Berlin, Florence, London: Euston, King's Cross, Liverpool Street, London Bridge, Paddington and Waterloo. Also the stations of Paris (Fig. 9.3) and Warsaw. Similarly, although it was not so frequent, some through stations also penetrated into the existing city (Bruges, Cologne, Konigsberg and Stockholm)).

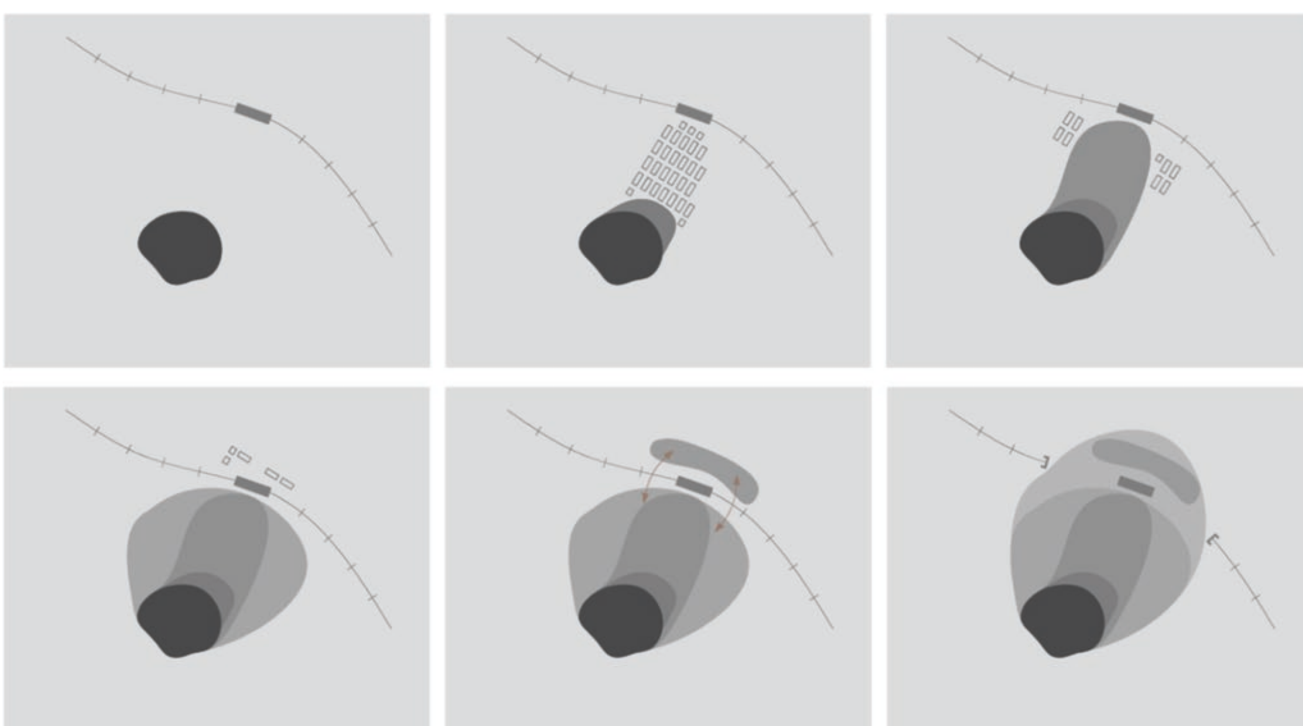

Fig. 9.2 Scheme of urban or peripheral implantation of the station and urban expansion. Guide for your GIS analysis. (Source: Álvarez-Palau et al. 2016)

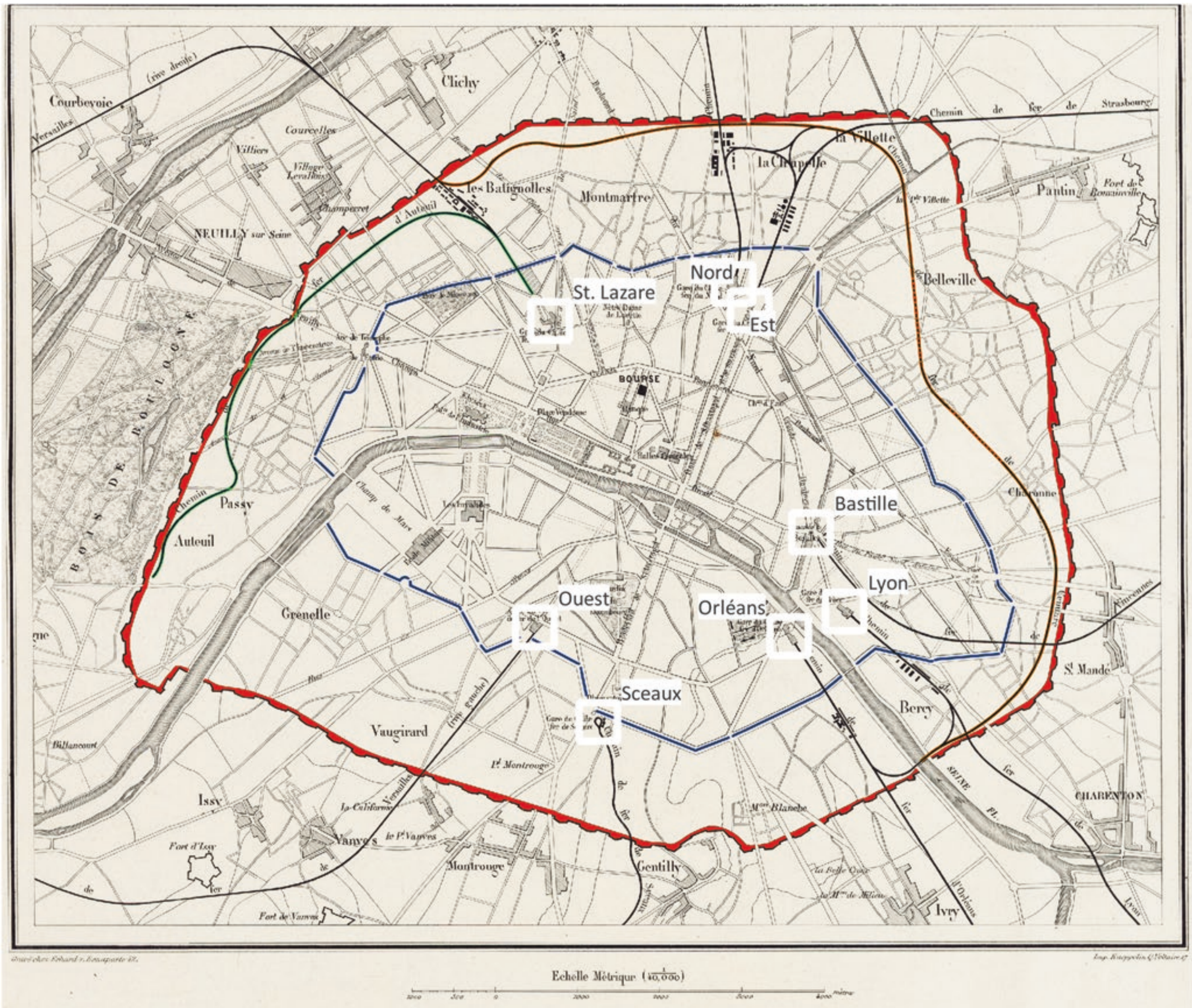

Fig. 9.3 Paris. (Source: own work and Schomburg (2013))

So it was that the railway station of the steam age mainly became located in a place close to the city, although outside of it. To be more specific, it tended to be located on its periphery, or a little further away, but preferably on publicly owned space that was ceded to railway companies. It is therefore an interesting line of study to elucidate its urban role in the decades after the inauguration of the new transport system, especially where there was space that could be transformed between the city and the station. The result of the analysis of this topic (Sects. 9.1 and 9.6) was that, in some cases, the station was located on the edge of the city, in the space left by the old walls (Amiens, Barcelona, Brunswick, Gothenburg, Metz, Turin and Zurich), or taking advantage of valleys next to the city (Edinburgh, Poitiers and Segovia) or even using tunnels to approach them (Angouleme, Genoa, Limoges, Lisbon, Lyon and Prague). A general outline of the relationship between urban growth and railway station location can be seen in Fig. 9.4, which is divided into six stages. This illustrative scheme allows us to observe the progression from the external establishment of the track and the station (1) to the construction of a promenade and buildings bordering upon it (2). This was followed by the expansion of this space (3) and the construction of the first buildings on the other side of the tracks (4). Following its consolidation (5), the tracks passing through the city were then covered (6). Naturally, each city has, however, followed its own evolution, and not all railway stations have followed exactly this pattern. However, when searching for these common patterns, one recent work (Solanas et al. 2015) applied vector analysis, and its methodology is detailed in the tutorial.

The information provided above allows us to deal more specifically with the issue of the new centrality associated

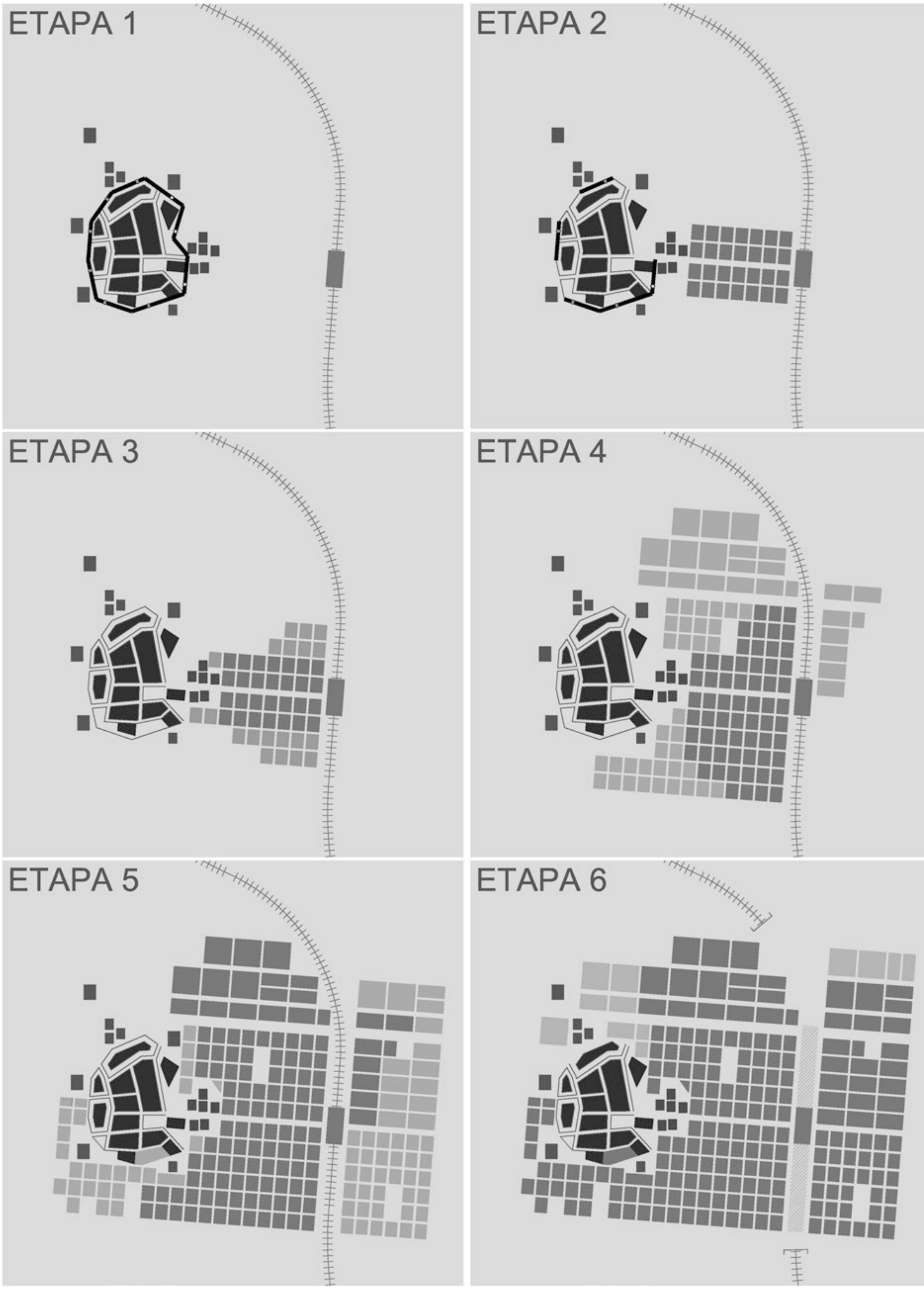

Fig. 9.4 Morphological model of urban growth of six stages in relation to the railway infrastructure. (Source: Álvarez-Palau et al. 2016)

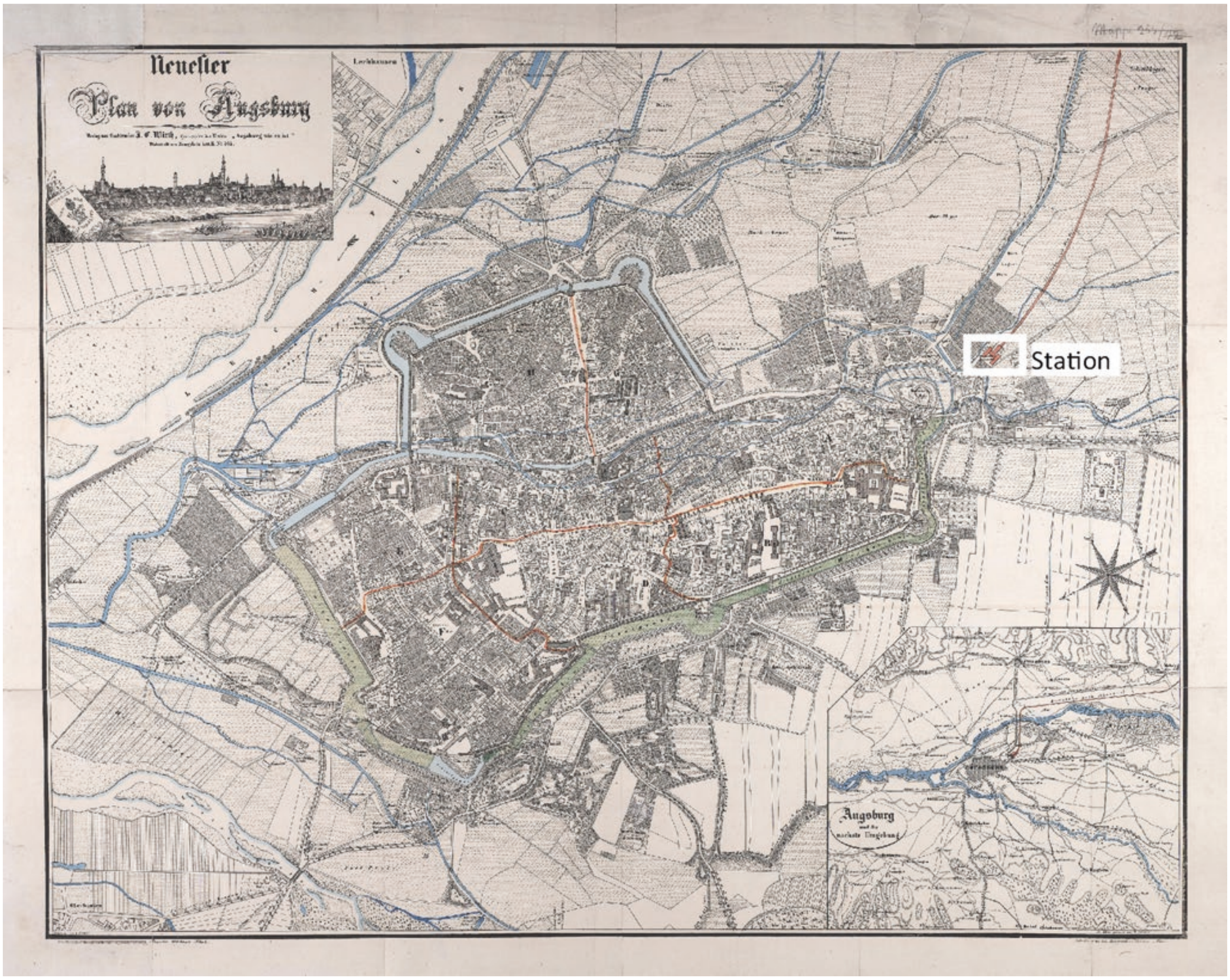

Fig. 9.5 Augsburg. (Source: http://tudigit.ulb.tu-darmstadt.de/show/Sp_Augsburg_1850)

with railway stations. Along these lines, the most general casuistry consisted of the station behaving as a relevant factor in urban transformation. This took place under the influence of the local ruling classes and mainly in the last third of the nineteenth century and at the beginning of the twentieth century. There are numerous examples of this amongst the cases already mentioned, but there are also others in Europe, such as Bari, Dresden, Frankfurt, Fulda, Grenoble, Kassel, Luxembourg, Maastricht, Magdeburg, Mainz, Milan, Strasbourg, Valladolid and Vitoria. The new centrality from the station was configured through global urban projects, or simply through the opening of streets, extensions, alignments and changes of use, in order to create a new, middle-class habitat. There were many cities in which the key factor was the opening of one or two streets from the station to the centre of the city, which provided urban axes for organising the new spaces. This was particularly clear in cities such as Augsburg, Bergamo, Béziers, Bremen, Córdoba, Erfurt, Fulda, Graz, Le Mans, Maline, Nevers, Nîmes, Oviedo, Padova, Parma, Perpignan and Rennes (example of Augsburg in Fig. 9.5), while in others, existing roads were converted into urban roads (Belfort, Clermont-Ferrand, Murcia).

In contrast, there were cities in which the station hardly changed the existing centrality. In some cases, a relatively short connection to the urban fabric was established (Burgos, Chartres, Ferrara, Innsbruck and Leiden); in others, the station was located on the very edge of the urban space and did not cause any relevant change to the existing city plan (Aachen, Brno, Istanbul, Utrecht and Vilnius). Other relevant cases of stations having little impact were due to the location of the railway station on the other side of a river (Bamberg, Rouen and Trier) or canal in relation to the urban centre (Carcassonne, Delft, Mulhouse, Saint Quintin and Toulouse), which either prevented or limited its urban influence.

So far, we have presented a way of studying the interaction between the railway station and the city, which has consisted of studying the effect of the station's passenger building on urban centrality. The theme that is developed in the following section complements this and deals with the creation of working spaces from the industrial installations linked to railway stations.

9.2 The Industrial Space of the Railway Station and Its Working-Class Neighbourhoods

When railway stations have promoted the emergence of large factories in the city, they have had two types of effect: they have become an obstacle to urban accessibility, and they have conditioned the social profile of their surrounding areas. This has largely been the case of mixed-use stations that have also included facilities for what has been referred to as "high-speed"[1] and "low-speed" freight services, locomotive depots or even general railway workshops (as in the case of Valladolid, amongst others). All these stations have occupied an area of land of considerable size, often covering tens of hectares, in what is now the central parts of their respective cities. In addition, they have had a "plug effect" with respect to their surroundings, when the city has expanded and surrounded the station. In the case of terminal stations, large areas of such land have emerged (Bordeaux, Copenhagen, Glasgow, Kassel and Madrid Atocha; Fig. 9.6), or more or less elongated spaces have been created, with the passenger building being located in an advanced position, or as a type of spearhead, to provide closer access to the city. In this way, freight services were left in more distant positions, and technical facilities were located even further away (some examples of this can be found in stations in large cities, such as Berlin, London, Marseille, Munich, Paris, Stuttgart and Turin). In the case of through stations, in some cases, they formed a rather compact area (Augsburg, Bremen, Karlsruhe, Lubeck, Magdeburg, Rennes, Salamanca, Strasbourg, Valladolid and Würzburg) or separated their spaces into differentiated areas (Chemnitz, Dresden, Düsseldorf, Hannover, Cologne, Milan, Stockholm and Zurich).

Particularly the workshops, but also the warehouses and centres of logistics, were railway facilities that received a lot of employment and activity. In some cases, they occupied areas of the mixed station itself or became individualised spaces, located further away from the city. In the cases of the

[1] High speed were the most expensive tariffs: passengers, luggage, messages and special products such as fresh fish or live animals. While low speed included tariffs for the transport of products that could circulate more slowly.

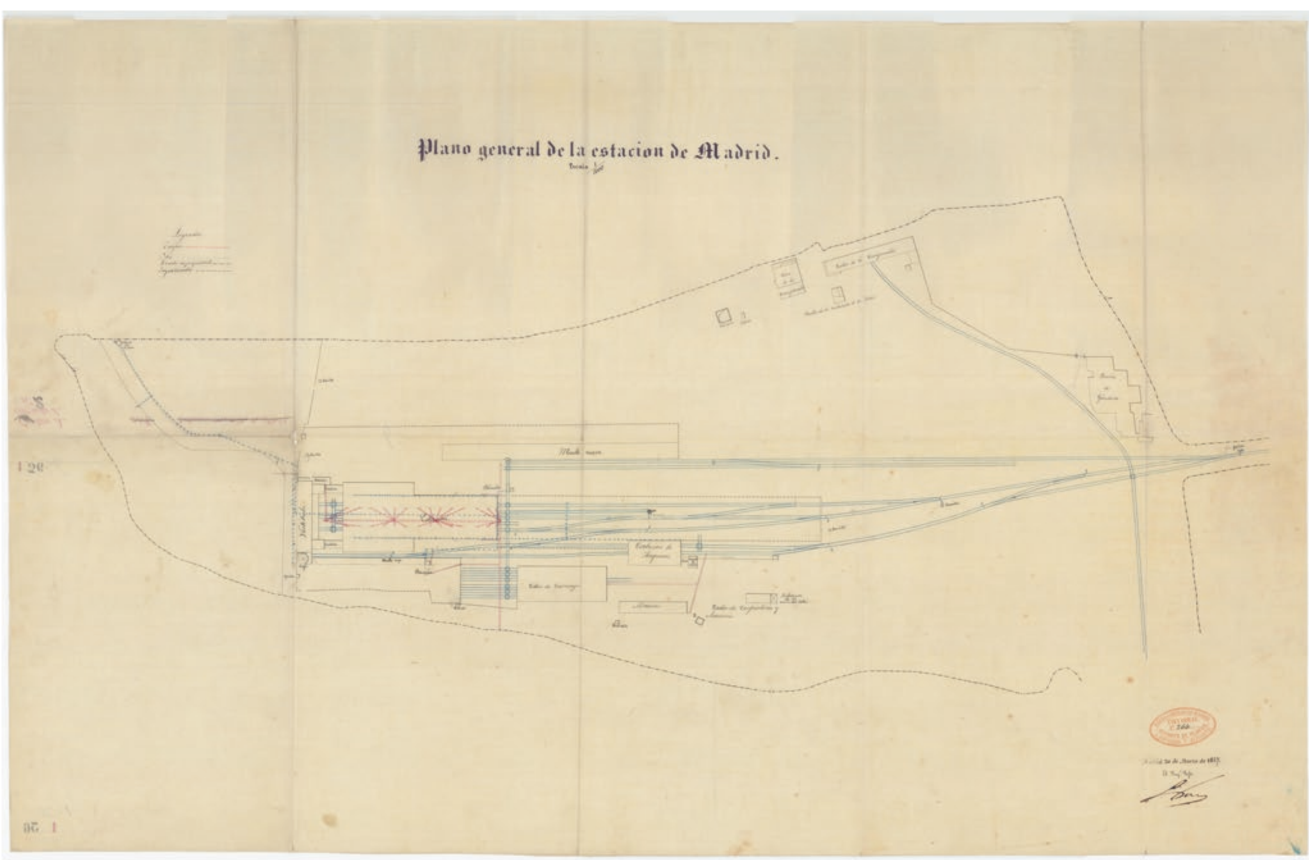

Fig. 9.6 General plan of Madrid station (Atocha), 1857. (Source: AHF-MFM)

most dynamic cities, these centres of activity later gradually moved to the periphery, both because they needed more land and because of road access and land value. In addition, the complexity of this type of station gave rise to the specialisation of commercial installations: coal stations, postal stations for mail, parcels and sorting, or even cold storage facilities (Paris-Bercy and Paris-Ivry).

The passenger building, or front part of the station, was therefore related to the urban centre, while the more extensive, and active, back part of the station was related to its trading, technical and productive facilities, with which it normally became a focus of attraction for working-class residents. This was the case, for example, of Paris-Nord and the Goutte d'Or neighbourhood (Clozier 1940) and of Madrid-Atocha, associated with the Las Delicias neighbourhood.

In addition, all the railway companies had buildings – dormitories for the traction staff next to the locomotive depots, particularly in the twentieth century – to house their employees and workers. These received different names in each language: *cités cheminotes*, railway-towns, *Eisenbahnstädte* and ciudades ferroviarias (Cúellar Villar 2018). They were built in the form of garden suburbs or as groups of residential blocks. Their sizes were diverse, ranging from a few dozen dwellings to up a thousand. There are thousands of such residential complexes for railway workers in Spain alone, so this was a major and widespread reality. They were not only built in cities but also in towns and formed relatively isolated areas, with direct links to the workplace. They were therefore built next to large warehouses (Altenhundem, Brou-sur-Chantereine, Longueau, Arroyo and Tergnier), or in nuclei with warehouses and general workshops outside the cities (Ashford, Crewe, Entroncamento, Hellemmes, Knittelfeld, Saint-Pierre- des-Corps, Sampierdarena and Swindon).

In short, an interesting way of studying the interrelationship between railways and cities is to analyse their proletarianisation effects in areas surrounding the work spaces of buildings for transferring goods, warehouses and workshops. In the next section, we change the focus and look at the impact of the railway station, and its annexed buildings, on the railway line.

9.3 The Urban Planning Role of the Railway Line, from Limit to Barrier

In a first stage of the introduction of the railway network in Europe, the tracks constituted a frontier for the city and were located at a distance from the built-up nucleus, providing a new horizon towards which to reach in its spatial growth. However, in the long term, and specifically after the widespread demolition of the city walls, the railway lines would become the city's new limit. In a first stage, it was therefore considered that urban expansion should fill up the space out to the railway line. However, before electrification, railways generated not only noise but also dense smoke. In addition, they attracted industrial and storage facilities. For this reason, railways often behaved as a deterrent to the bourgeois habitat. Thus, and as has already been pointed out, although the passenger building was, from the very beginning, an attractive focus of centrality, this was not the case for the rest of the railway. For this reason, urban growth near the railway tracks and industrial facilities was, more often than not, more typically associated with a working-class habitat, which occupied the less valuable spaces. This was the case in general, with clear examples being provided by Valladolid and Montpellier. Even so, there were exceptions, such as Upsala and Darmstadt, where the area of expansion had already been built before the arrival of the railway. It is therefore relevant to analyse long-term urban dynamics, both before and after the inauguration of each railway station and line, in order to interpret the impact of railways.

This long-term vision allows us to establish at what point the growth of the city crossed the limit set by its roads, which thus saw their urban role transformed. The railway line thus became a barrier for which solutions had to be found so that road traffic would not be limited by it. If the previous city wall had established a separation between the city and the countryside, the railway established a clear barrier between the consolidated city and the suburban working-class neighbourhood (which was called, according to the language, faubourg, quartiere operaio – sobborgo industriale, vorort der arbeiterklasse – vorstadt or working-class suburb). Thus, the railway reinforced the centre-periphery model. This gave rise to different areas of urban fabric, on one side and on the other of the track. For their part, the old highways and roads became organising axes for leaps in growth, which were usually unplanned.

In the case of the most dynamic cities, the railway posed a serious barrier problem that affected urban development. This explains why work to bury railway lines began as early as in the nineteenth century, despite the fact that, with steam locomotives, this meant that passengers had to endure their smoke in long tunnels.[2] Although urban tunnels were built from the very beginning of the railway (such as the Wapping tunnel, at Liverpool, or the Primrose Hill tunnel, in London), the burying of the railway as it passed through the city was a complex problem that only electrification could solve. Each

[2]There were railway tunnels almost from the very beginning of railways, but short ones implied acceptable problems such as going fast, closing windows and having ventilation chimneys and ventilators in the tunnels.

case was different,[3] but, in general, with the exception of some central stations, railway lines have tended to remain on the surface. As a result, in both large and small cities, railway tracks continue to constitute a barrier.

A relevant perspective from which to analyse the historical relationship between the railway and urban growth is therefore the influence of the railway line on urban planning which, as we have seen, passed from being a limit to a barrier. In summary, the barrier effect of the railway has had three dimensions: (1) the closure of the urban fabric by the railway line, which can only be crossed via its railway crossings; (2) the fixing effect of the line for urban zoning and, above all, for socio-spatial segregation; and (3) the border effect, in the sense of forming a separation between the two sides of the railway. We shall now go on to look at the different solutions used to overcome this barrier effect.

9.4 The Problem of Railway Crossings

The railway line became a new linear infrastructure that obstructed previous communications which, at the time of its construction, required the introduction of railway crossings (in the form of tunnels or bridges). However, given their cost and their negative impact on railway functionality, only main roads and very busy routeways were able to use them. Initially, this cutoff effect only had a few significant implications in terms of the city's communications with its surrounding area and immediate territory. However, when the urban fabric expanded to the other side of the tracks, the problem also became intra-urban. The barrier effect of the railway implied an urban problem because it categorically separated one part of the city from another; this was something that could only be mitigated by increasing the number and quality of crossings. In addition, it was a railway problem because it affected the safety of railway traffic and implied higher costs due to having to provide guarded level crossings and technical equipment. For this reason, the railway companies tried to keep the number of level crossings down to as few as possible, with the consequent danger for pedestrians.

Throughout the twentieth century, the problem of level crossings was aggravated by population growth, urban expansion and the increase in road traffic. Although the crossings offered connection, the intensification of their use turned them into bottlenecks, and they became synonymous with congestion. The increase in the accident rate at level crossings, and their negative social consideration, made them a focus of political attention. They therefore had to be replaced by underpasses to increase transversal accessibility. However, making this a reality was a slow process due to the complex distribution of economic responsibilities between the railway companies, municipal authorities and the state. On top of this, in many cases, there was not enough space to transform the railway crossings.

This problem of the permeability of the railway line when the city had passed to the other side first attracted the interest of managers and the public in the fastest growing cities. Calls from citizens for the transformation of railway spaces into public spaces continue to be the subject of debate.

A relevant way of approaching the analysis of the relationship between the railway and the city is therefore to analyse the limiting effect on the initial urban growth, to study its evolution towards a barrier effect, when the city spread to the other side of the tracks, and finally to analyse the problem of transverse crossings as obligatory nodes of passage and consequently as bottlenecks (Santos y Ganges, 2020). In short, the impact of the railway on the city has been one of spatial segregation, which is a theme that we will develop in the following section.

9.5 The Railway Line as a Tool for Spatial Segregation and Creating Social Barriers

As it passes through the city, the railway line acts as a very evident urban boundary; due to its barrier characteristics, on numerous occasions, it has served as a line for separating different land uses. Without the need for urban planning, railway lines have always marked differences in land process because "the other side" has been worse communicated. This explains why factories and warehouses associated with the railway were built there, and this area was also chosen to house workers.

Along these lines, *zoning* has become a habitual urban planning practice of local administrations, since the beginning of the twentieth century, independently of, or even incorporated within, official urban planning. What started as functional zoning, which separated incompatible activities, later served as a tool for stabilising the property market and adopted segregating interests (Mancuso 1978). Zoning has been a tool to separate different types of uses based on land prices and, as a result, has produced socio-spatial segregation.

[3] In Brussels, the burying of the *ligne de ceinture* took place between 1881 and 1915. In 1882, the trench level of the railway line in the Ensanche de Barcelona was reduced so that it would be less of a nuisance; the line was finally buried in 1962. In New York, during the period 1903–1913, the Grand Central Depot was completely rebuilt as the Grand Central Terminal, and between 1904 and 1910, Pennsylvania Station was built, both with underground railways with electric traction.

Railway lines have been a factor in segregation, both effectively – following the basic rules of the property market – and even officially, through deliberate urban planning. In some cases, there has been evidence of both phenomena: first, the de facto effect and then regulated segregation, within the process of using the railway line as a differentiating infrastructure. Jane Jacobs (1961: 257) put forward the idea that tracks constitute a classical example of a *social border*, which is clearer in small and medium-sized cities than in large ones. The casuistry in Spain is one of the clearest in Europe, as railway lines have had a clearer differentiating effect between social classes than elsewhere and over a longer time. In Spain, Córdoba, Palencia and Valladolid provide clear examples of the railway acting as a social frontier (Santos y Ganges 2007).

Regardless of the segregating role that was soon attributed to railway lines, it is clear that living near to the railway implied certain problems relating to quality of life. The passing of trains caused inconveniences, even at night, so the market value of space near to the tracks was always reduced. Thanks to the electrification of the trains and the intense motorisation of the streets, living near the railway track gradually lost the brand of being the only place affected by noise.

On many occasions, buildings were constructed with their backs to the track, but they were positioned up to the limit of railway space. On the contrary, having streets that run parallel to the railway lines has always been a good urban planning practice (see Fig. 9.6 relating to Atocha). This did not always separate residential buildings from the trains, but it also allowed better street connections and relations with level crossings. On its passage through the city, the railway corridor had to have lateral enclosures in the form of continuous railings or walls where the previously mentioned streets ran parallel to the tracks. These presented the problem of being streets with only one façade, which therefore became part of what Jane Jacobs called *the curse of border vacuums*, or, in other words, they had very little vitality.

> In the case of a railroad track, the district lying to one side may do better or worse than the district lying to the other side. But the places that do worst of all, physically, are typically the zones directly beside the track, on both sides. Whatever lively and diverse growth occurs to either side, whatever replacement of the old or worn-our occurs, is likely to happen beyond these zones, inward, away from the tracks. The zones of low value and decay which we are apt to find beside the tracks in our cities appear to afflict everything within the zones except the buildings that make direct, practical use of the track itself or its sidings. (Jacobs 1961: 257–258)

Every urban frontier must annul the social life and simplify the use of the urban space, in such a way that near to it, there is a reduced mixing of people, fewer users and fewer elements differentiating its use. If we add to this the limited quality of the areas bordering the railway, it is possible to understand that the curse of this type of frontier was very intense.

As a general framework, we should remember that the history of the railway must be interpreted as the result of two forces that sought to condition its development: railway companies and public powers, which were represented by the state and the municipalities. However, the railway entered the society and economy of the nineteenth century with such force that the companies were effectively able to wield their power virtually unilaterally during the first period of railway development. This was reflected in the thinking of Abercrombie (1998) when he referred to its origins:

> Hailed as the prime symbol of industrial success and so armed with despotic powers, they [the railways] became a new tyrant dominating our cities with much less regard to the general convenience than the old aristocratic planner … High embankments cutting off normal growth, level crossings holding up traffic, ill-placed railway stations, wastage of valuable central space for sidings – these and many more are the disadvantages resulting from the railways having been considered apart from general urban planning requirements. (Quoted by Purcar 2007: 342)

The previously mentioned considerations make it possible to reflect on the fact that the railway did not only have positive effects, which makes its global evaluation complex. If we consider the fact that art is reflected in different ways of looking at the reality of a society, painting can give us some clues as to how this new phenomenon was seen at the beginning of the railway age. J.M.W. Turner was the first great artist who showed interest in the arrival of this new machinery. In Fig. 9.7, it is possible to see one of his first paintings, which transmitted a feeling of ambivalence. On the one hand, the railway appears as the most powerful manifestation of technological progress. However, on the other hand, its smoke invades nature, suggesting concern about the

Fig. 9.7 Turner painting. (Source: Turner 1844)

effects of this innovation. Turner often offered ambivalent messages in his work, which forced the spectator to reflect.[4] Throughout the history of modern art, there have been many manifestations of interest in the railway (Purcar 2016)[5]; this is a subject that deserves specific research of its own. Another way of focusing study on the impact of the railway has been through H-GIS studies. In this case, it will be possible to make a more precise study of the influence that railway stations have had on urban development.

9.6 GIS Analysis of the Station and the City

In this section, we shall return to some of the aspects that have previously been presented in order to highlight the transforming impact that the station had upon the city. We shall show some examples with the help of maps and figures and, in particular, studies that have used H-GIS. In the theme of the impact of the railway upon the city, GIS allows a comparative analysis between cities throughout their history. The potential and interest of this type of analysis depend on the quality of the sources that are needed to construct a H-GIS.

Studies of the transformation of cities as a result of transport infrastructure (roads, ports and railways) have traditionally described the changes in their morphology as a result of the actions of specific agents (municipalities or construction companies) or general factors (population and the economic environment). These works have been supported by maps, photographs or other documents that illustrate these processes.

The analysis of this same theme using the tools made available by GIS makes cartographic sources instruments for analytical work, rather than using them to illustrate a particular discourse. There are numerous works on this subject, but there are two examples that refer to the same city: Lisbon, which will allow us to evaluate this change. On the one hand, Maga Pinheiro dedicated various chapters of her book "Cidade e caminhos de ferro" (2008) to studying the transformation of the city as a result of the introduction of its railway stations and the opportunities that the railway connection provided. In a more recent study, Pinho and Oliveira (2009) used digital cartography to describe and analyse the evolution of the built-up area in Lisbon. This called for the creation of a database based on archive information relating to the years in which each building was constructed. These are, therefore, two different, but equally valid and complementary, ways of investigating the same subject. However, digital cartography allows quantitative and visual comparisons of the phenomena studied, at different scales.

However, work done on this subject in GIS has been carried out in a very different way. We shall now go on to present some examples, which provide valuable clues for its future development, and in the adjoining tutorial, it will be possible to look at some of these in greater detail. Along this line, it should be stated that part of the current interest in historical knowledge of the relationship between the railway and the city is based on the relaunching of rail transport in Europe, thanks to high-speed rail. One recent study (van Acker and Triggianese 2021) bears witness to this. In this work about the design and insertion of railway stations in modern Dutch cities (the Netherlands), great attention is given to the development of cities analysed from the eighteenth century until the present day. To do this, the authors used GIS and CAD programmes.

Another line of study has been carried out by Cristina Purcar who, as we have already seen, has analysed the different forms that urban expansion has taken starting from railway stations, which were always located outside the urban nucleus. Purcar shows how the growth of cities can, to a large extent, be explained by the railway effect. She shows that the city has gradually swallowed its railway infrastructure, although she also points out "the failure to render the railway barrier permeable and to generate complementarity rather than subordination between the two sides of the track" (Purcar 2010: 66). In general terms, one of Purcar's conclusions is that:

> Systematically located at the urban fringes, the railway boundary invested the peripheries with new meanings, often challenging the previous front-back or public-private configurations. New accessibility and visibility conditions were established between settlements and their agricultural hinterlands or their waterfronts, while the new railway frontier redefined the urban margins, inserting a new public venue open towards the peripheries, unlike the roads that traversed the town or village centers. (Purcar 2012: 396)

This work allows us to show the interest in presenting historical sources in automatic cartography in order to achieve analytical results. To check this, we can present some of the cases examined by Purcar for the period 1868–2000. These maps clearly show the year in which the railway stations and lines opened and also the stages of their expansion. As we will see, the causes vary. In Fig. 9.8, it is possible to observe the expansion of Arad and Simeria, which took place around their respective stations, which were also located in areas with available land.

The case of Alba-Iulia is very different (Fig. 9.9), as the development took place in the area of the city opposite the station. Finally, the case of Radna (with the city of Lipova on

[4] This also occurred in his work, in which a new steam ship tows an old sailing ship, which had been a hero of the Battle of Trafalgar, to the scrapyard: The Fighting Temeraire by J. M. W. Turner – Montys Minutes, YouTube.

[5] In the blog http://arteyferrocarril.blogspot.com.es/, it is possible to visit a large amount of artistic material referring to railways, which is organised by themes.

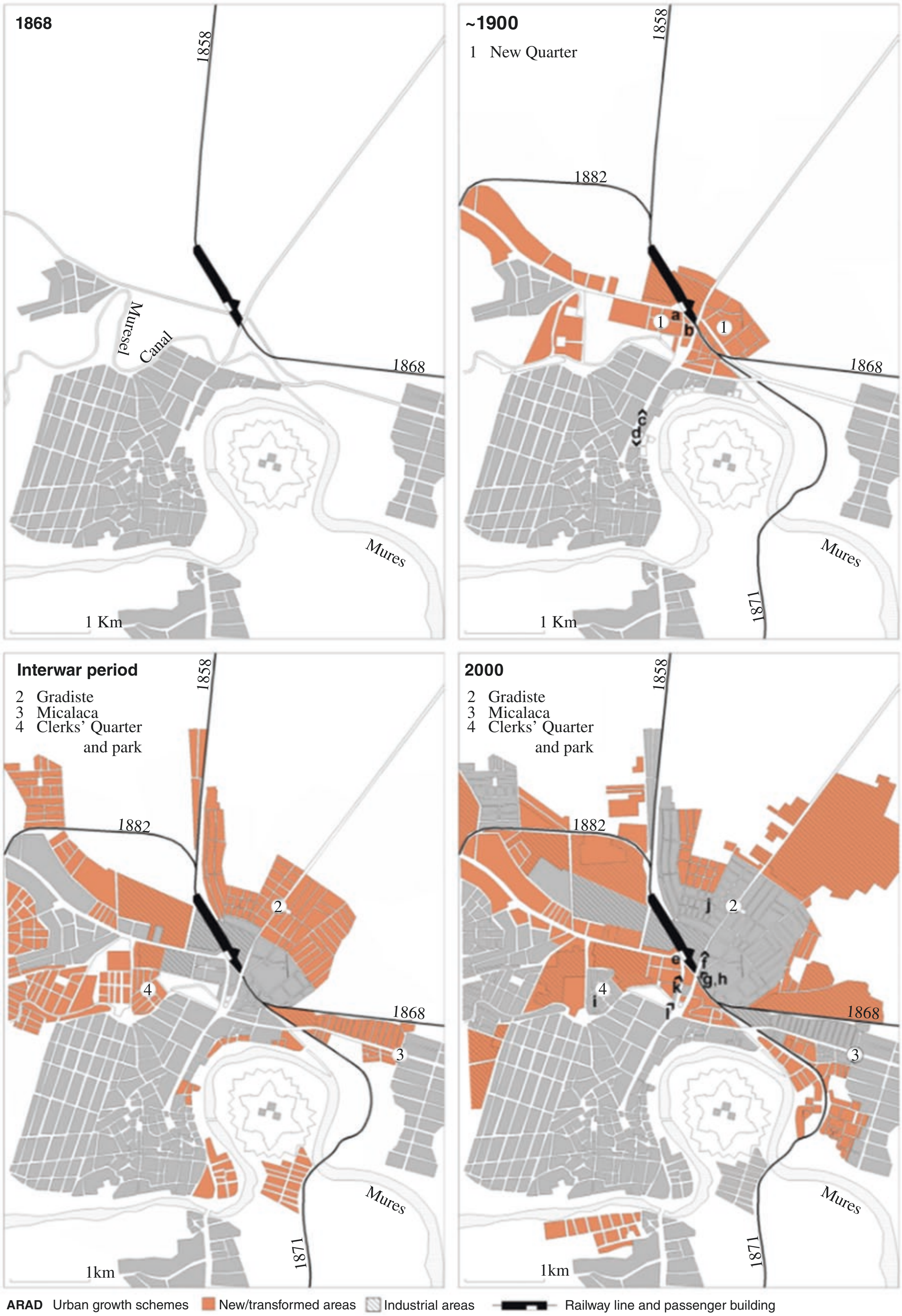

Fig. 9.8 The expansion of Arad and Simeria. (Source: Purcar, Cristina)

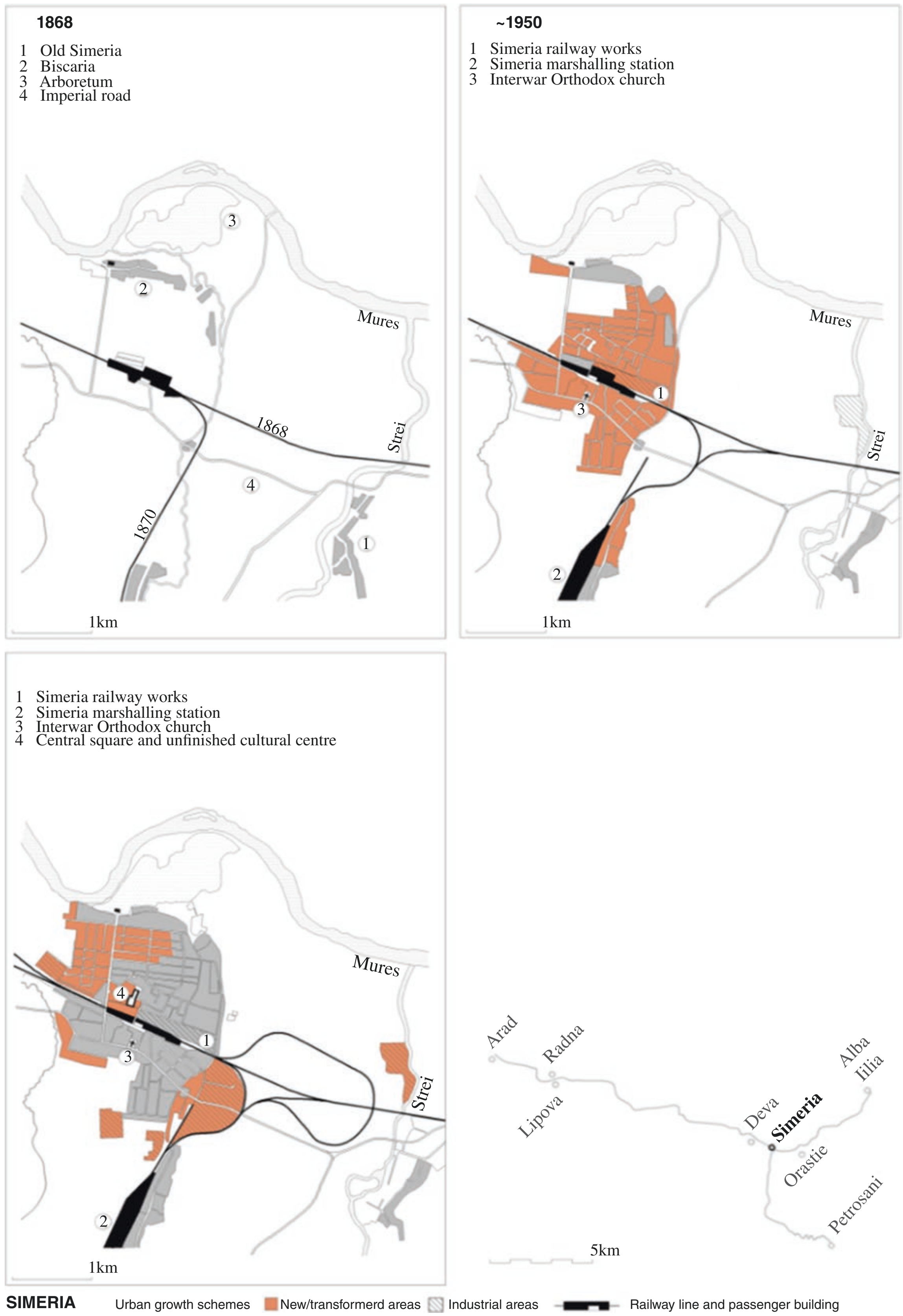

Fig. 9.8 (continued)

Fig. 9.9 The expansion of Alba-Iulia. (Source: Purcar 2009)

the other side of the river Mures) is that of a station in an already urbanised area, with the old cities on both sides of the river, so expansion took place along the Mures, in Lipova, at a certain distance from the railway station (Fig. 9.10).

In a similar line, the *Atlas of the Dutch Urban Landscape* (Rutte and Abrahamse 2016) – which is also studied in Chap. 12 – specifically examines the relevance of the railway in all of the 35 cities studied. In each monographic chapter about them, and in a comparative annex, the authors have produced specific graphics in which they highlight the presence of the tracks and of the railway stations on a cartographic base which shows both the evolution and the characteristics of the urban fabric. The commentaries that accompany these 35 figures are perhaps the best expression of a complete analysis applying H-GIS to the cities in a country, which provides comparable and significant results. The information about railways is incorporated into what they call "outline maps", which are the result of an innovative approach. In technical terms, this atlas is available via the *Web Feature Service* (WFS) service, which means that it is possible to consult geographic objects provided in a standard format. This means that it is possible to make searches for attributes (such as a city) and to consult the associated table from GIS software. It also makes it possible to download spatial databases in order to work with them at the local level. This involves working with polygonal data vectors. The table has a field for the year in which the plot was built upon and a field corresponding to the municipality. There are also symbol patterns with which to visualise the plots according to the year of construction, with a red tone for the older plots and a blue one for the more recent ones. If the user wishes to add layers for (railway) lines or points (for towns and cities), this can be done by adding the corresponding layers.

The thematic maps of this Atlas were the result of the objective to "incorporate the various factors we encountered [which were] field patterns, rural roads, and infrastructural elements like water, railroads and motorways" (Rutte and Abrahamse 2016: 14). In the comparative annex, the authors conclude that:

> Truly profound changes occurred when railways arrived […] the focus of many towns shifted from the waterfront to the railway; in a sense, they turned around. In the decades around 1900 most urban expansion and development occurred in the direction of the railway stations, which in most towns were situated on the opposite side from the old water-based infrastructure. Fortifications were dismantled and transformed into boulevards, recreational parks and pleasant residential areas. Only in Uthecht (Figura 11), Groningen and Deventer were the town moats partially retained; in all other towns they were filled in. (Rutte and Abrahamse 2016: 166)

Two of the synthetic maps from this atlas are particularly significant for our interests. On the one hand, there is the map entitled "The largest towns in 2010 and infrastructure. Urbanisation and water courses, AD 100 to 1500" (Rutte and Abrahamse 2016: 175), which highlights the perfect coincidence between the main cities and their access to the sea and/or to navigable waterways. On the other hand, that entitled "The largest towns in 2010 and infrastructure. "Urbanization and railroads system, 1850–1950" (Rutte and Abrahamse 2016: 215) shows the new industrial and residential towns located at railway communication nodes (Fig. 9.11). Finally, the example of the city of Amsterdam (Fig. 9.12) is a rather special case because although its growth has been linked to the presence of various railway stations, the well-known central station did not result in any expansion of the urban fabric in its immediate surroundings due to the fact that it is located between the river and the historic city.

Finally, we refer to a third line of work, whose main objective is to develop a specific methodology that makes it possible to quantify the historical evolution of the urban fabric of cities in relation to their railways. As has been shown in this chapter, the majority of the literature has studied particular cases and has described the urbanistic evolution in each case. This methodology, however, seeks to provide an approach for measuring the impact of the railway station through the form that urban expansion takes. To do this, it starts with a compilation of historic urban maps, their subsequent digitalisation using GIS, and the implementation of vectoral GIS indicators on georeferenced data. This procedure, as we shall see in the tutorial, makes it possible to interpret the process of the expansion of the urban area.

9.7 Tutorial

The morphological growth of municipalities over time is a matter of geographic interest. Into which spaces do they grow, and why? Is there a predominant direction of growth? There are many different factors that are involved here: transport infrastructure, relief and the hydrographic network.

In this chapter, we will focus on the railway network and, to be more precise, on railway stations. The hypothesis is that municipalities grow towards the railway station, once this has been constructed, as this is a central point that offers the local population a series of advantages. The most evident of these are a transport service and the dynamisation of activity in its immediate surroundings.

We will examine this phenomenon in the exercises in the current chapter. We will create the growth vector for two cities: Girona and Groningen. As we shall see, the growth vector is formed by centroids of the constructed nuclei municipalities (two centroids, for the year in which the study began and that in which it ended) and the axis that links them.

The final objective is to either validate, or refute, the hypothesis concerning whether the municipalities have grown towards the railway station or, on the other hand,

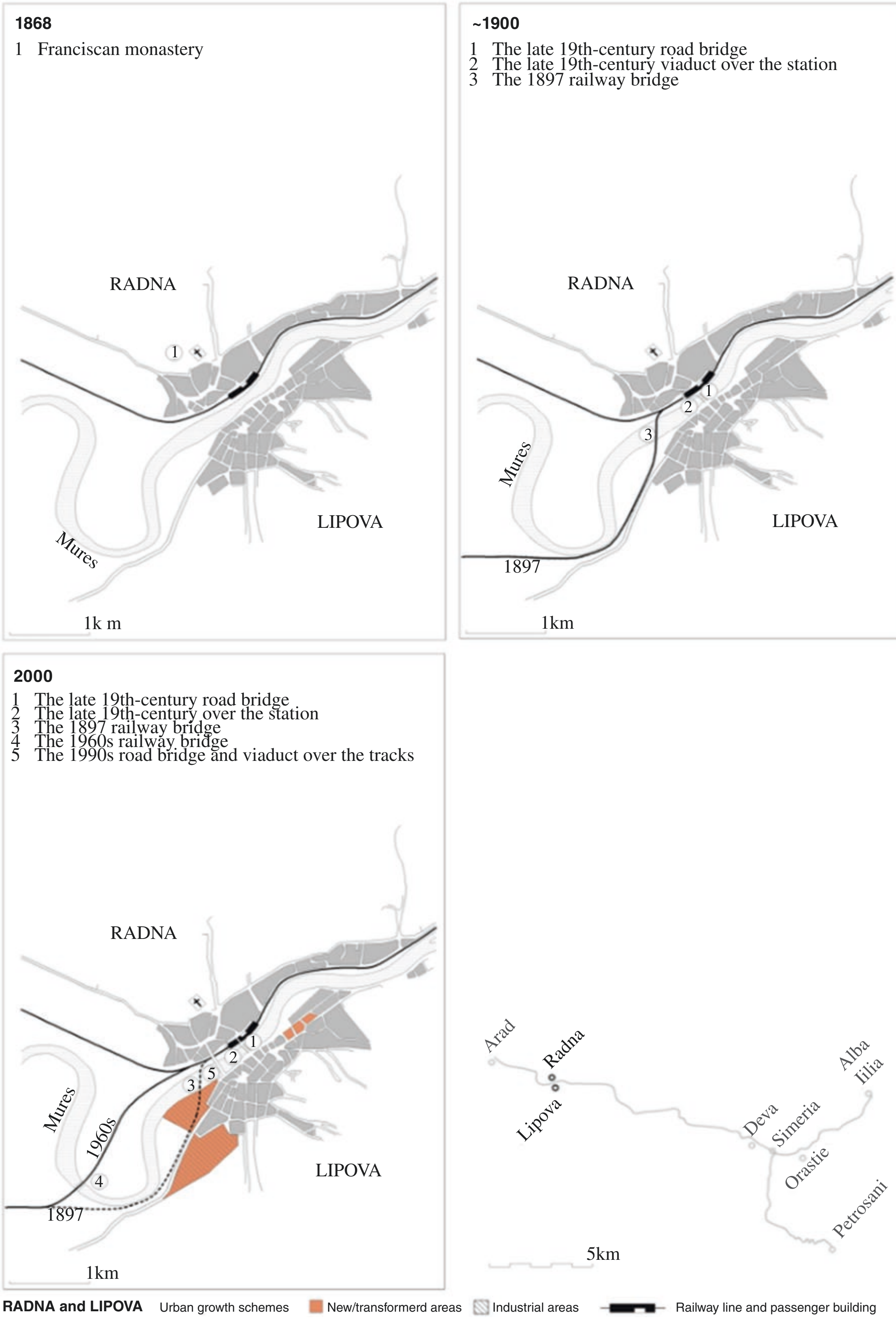

Fig. 9.10 The expansion of Mures Lipova. (Source: Purcar 2009)

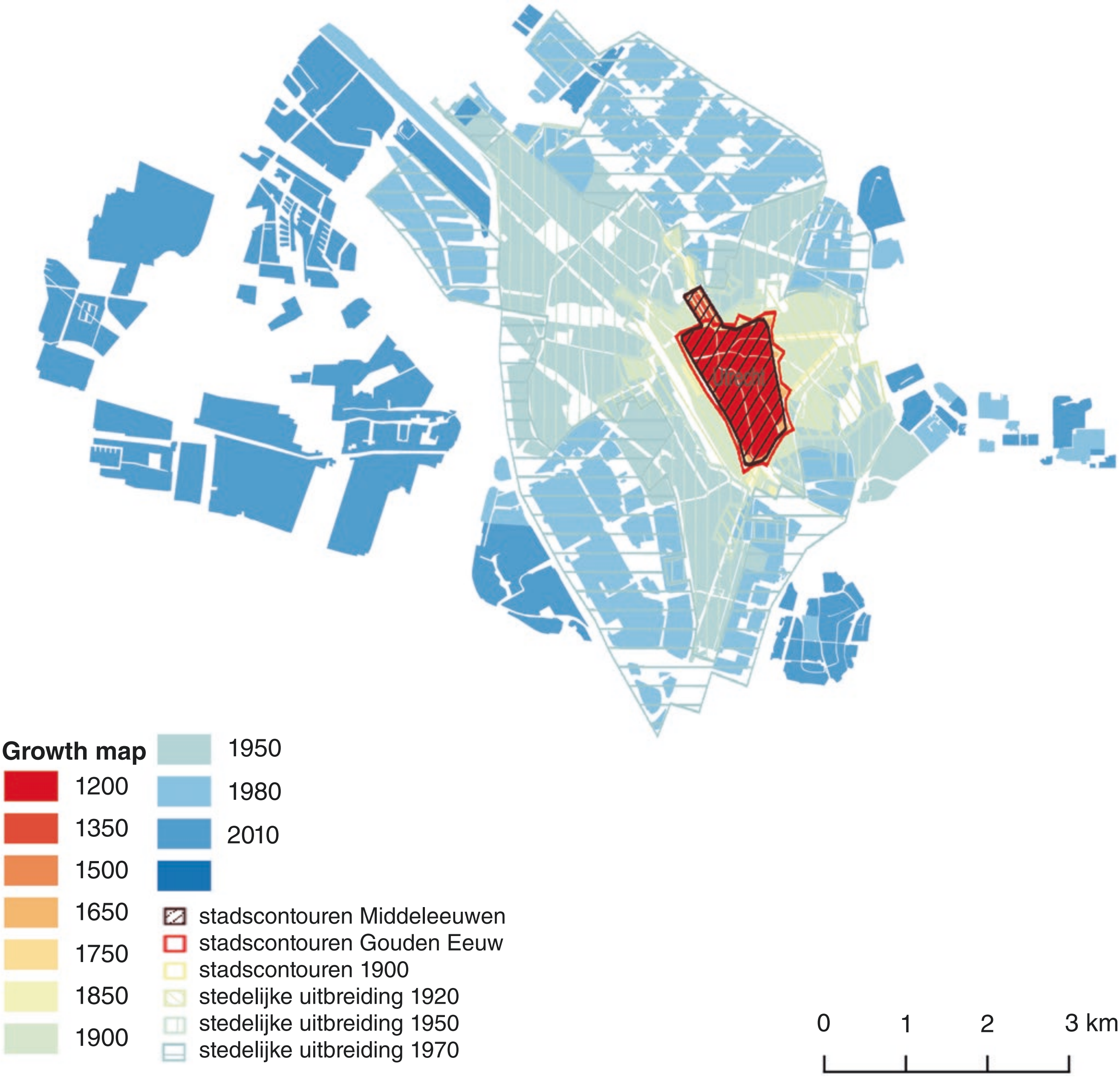

Fig. 9.11 Utrecht. (Source: Abrahamse and Rutte 2015)

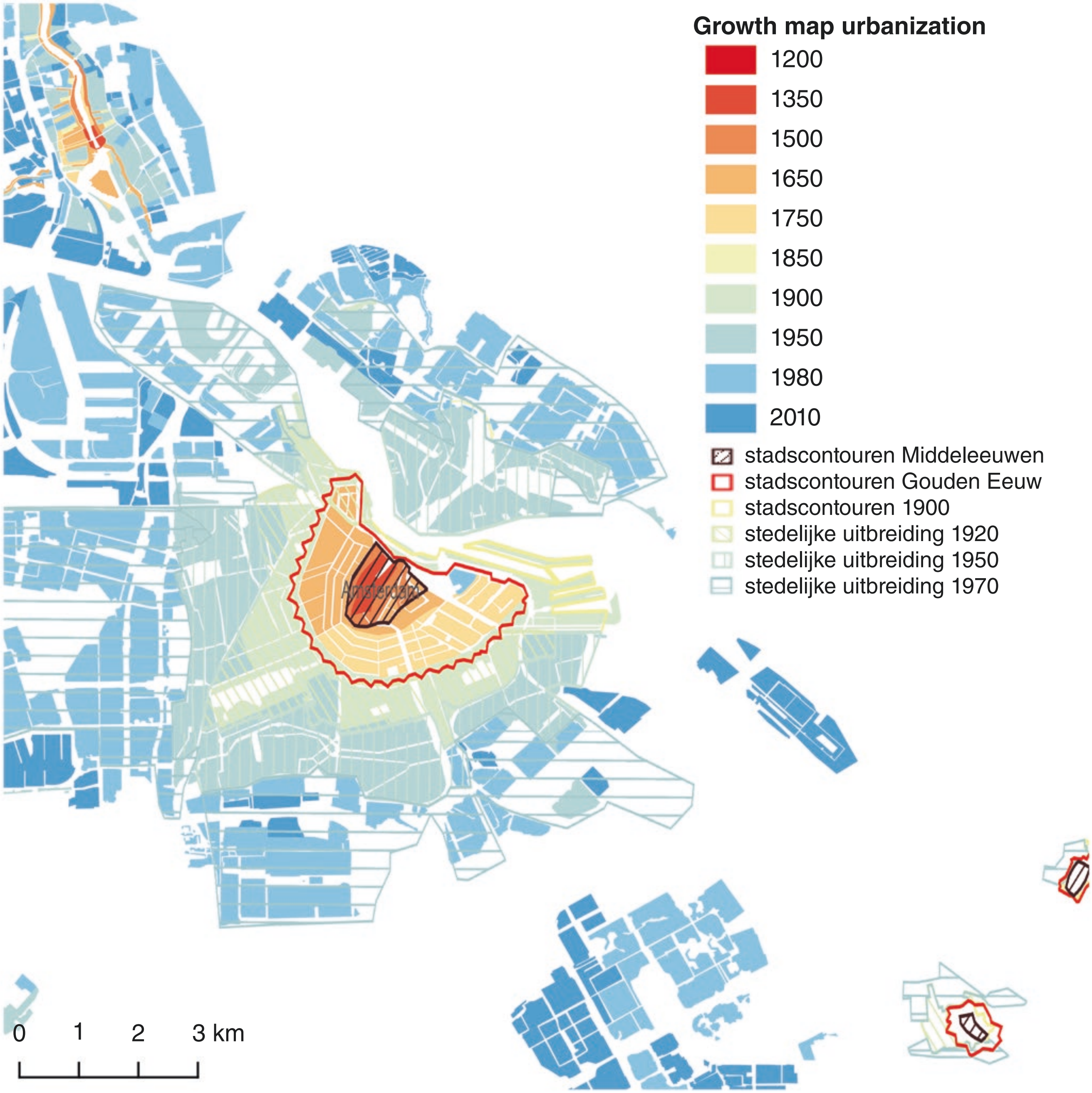

Fig. 9.12 Amsterdam. (Source: Abrahamse and Rutte 2015)

whether growth has not been in any specific direction. In order to discuss this hypothesis, it is, however, necessary to look at a large number of cases. This has been explained in the chapter dedicated to Spain. It has also been shown how readers will be able to carry out similar exercises in other cases that they may wish to study.

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10 Railway Stations

Guillermo Esteban-Oliver and Jordi Martí-Henneberg

Abstract

Wherever it is located, the railway station is a point of reference: both for the traveller who arrives in the city and also for users who are going to the train. In this sense, for railway companies, it constitutes a prestigious asset, especially in the case of stations located in the largest cities. Its architecture should therefore make it a recognisable point of reference for the public and a catalyst for new technologies.

Given their clear and concrete location in space, the study of railway stations provides a good opportunity to reflect upon the importance of the challenges associated with historical studies and, in particular, with those that consider the spatial dimension of this phenomenon over time.

Keywords

Railway station · Spain · Britain · Europe · H-GIS

10.1 Introduction

Given their clear and concrete location in space, the study of railway stations provides a good opportunity to reflect upon the importance of the challenges associated with historical studies and, in particular, with those that consider the spatial dimension of this phenomenon over time. The difficulty of integrating the geographical dimension into the interpretation of historical events has been a constant challenge for as long as the two disciplines have coexisted on the intellectual landscape. In fact, Immanuel Kant (1724–1804) reflected on these questions in an essay in which he highlighted the need to combine two basic axes, time and space, in order to interpret the phenomena of the outside world.[1] These two perspectives have evolved in parallel, but rarely in a combined and coordinated way. The manifestations of this enforced collaboration have depended on the schools of thought involved, the methodologies used, the training and interests of the authors concerned and the topic addressed. However, despite the importance of this valuable legacy (Martí-Henneberg 2013), it is only in the last 20 years that a powerful instrument has emerged that has been able to facilitate and consolidate this collaboration: the use of GIS in historical studies (Knowles 2008; Gregory and Ell 2007). It has been this development, and its strong empirical base, that has ushered in the use of historical-GIS (H-GIS). In this context, the theme of railway stations offers a good opportunity to assess the potential use of GIS in studies with a spatio-temporal perspective. The aim of the following list is to show the reader the different avenues of research that are available for future research in this field:

1. Stations are concrete elements in space whose importance can only be interpreted in historical terms and by considering different geographical scales. Their study makes it possible, and indeed obligatory, to integrate local and monographic approaches into a coherent and well-organised holistic study of the national and European rail networks.
2. More specifically, combining different scales of analysis gives greater meaning to studies that integrate information about stations with that relating to the whole railway

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[1] Kant reflected upon geography and history (space and time) between 1757 and 1797, a period in which he taught the subject of physical geography at the University of Könisberg.

J. Martí-Henneberg, *Creative Ways to apply Historical GIS*, https://doi.org/10.1007/978-3-031-21731-9_10

network. This makes it possible to relate the smaller scale, of the setting of a given station at a particular location, to the larger scale, of the connection of this location, via its station, with other places within its region, state and/or continent.

3. Similarly, studying railway stations makes it possible to combine qualitative and quantitative approaches in order to achieve an appropriate understanding and study of reality.
4. The information that can be associated with stations highlights the interest of using databases and their potential for promoting innovative research and teaching.
5. This also promotes the potential for conducting work involving cross-curricular collaboration. This is particularly interesting because the impact of railway stations can best be interpreted with the help of other data relating to their areas of influence.
6. It is possible to promote interdisciplinary studies at different levels. A given station can be studied from such diverse perspectives as its architecture, heritage, engineering or impact on mobility, with the possibility of combining different sources of information.

   At the same time, studying railway stations allows great thematic flexibility. It is possible to undertake studies centred on a specific railway company in one country; on a group of stations in a given city; or on certain types of station, such as those located at ports or built for new high-speed train services.
7. The study of railway stations makes it possible to organise debates on a range of different themes, including different ways of life associated with the general spread of rail transport, or the impact of stations on urbanisation.
8. For those researching railway history, before the advent of GIS, information about stations was normally limited to a list of names and was difficult to analyse. However, when it became possible to incorporate data in the format of a GIS dataset, new possibilities for study emerged. In this new context, railway stations have, for example, become the protagonists of works about the spread of the influence of the railway within a given territory. Such work can be undertaken from various angles, such as considering stations as the result of the strategic decisions made by each company, or as nuclei whose dynamism can be quantified at the local level through its association with the evolution of population and economic activity.
9. The historic study of railway stations reveals how many modern-day debates had already taken place in the past, for example, those relating to investment in new stations for the high-speed train (HST). Building a railway line also supposes making a cut across a territory; this can cause inconveniences that must be assumed and minimised, and this is also a subject for debate in modern society. Establishing a new railway station should not automatically imply diseconomies, if its management is up to standard. This is not, however, always the case, so the debate remains open as to the effects of stations and tracks on the territories and populated areas in which they are found.

In short, GIS facilitates both the localisation of each station in a given territory and assigning attributes, relating to different themes, associated with the X and Y coordinates of each station. For an appropriate interpretation of this information, it is also possible to associate it with environmental or socio-economic indicators relating to its immediate area. This allows the user to read and use these data at different levels. In fact, this chapter also makes a significant contribution to the field of railway history because – somewhat paradoxically – previous studies conducted in this field, in Europe, have almost exclusively focused on the railway network as a whole[2] when, in reality, the station is the most essential element of such networks. This is because it is at the station that all the other activities associated with railway services, such as the mobility of people, trade and industry, converge. While railway lines constitute the essential infrastructure, they would have no meaning at all if they were not associated with an appropriate network of stations, within a well-organised hierarchy. Given that the function of a railway is to interconnect different population nuclei, commercial and industrial activities and raw materials, this hierarchy must allow an equilibrium between rapid communications between the said nuclei and the presence of intermediary stops, which may help capture more business, but which also tend to slow down transport between the main nuclei.

In the following sections, we shall examine several questions which seem relevant to us. We shall do this in the following order: the typology of stations; their study within the context of the digital humanities (DH); their strong presence in the world of art, as a reflexion of their social importance; the case study of Barcelona; and then, in the field of GIS, a guide to how we created the GIS of Great Britain. The practical exercises will refer to the specific case of Spain. These last three sections have been included as an example and guide for their eventual application in any city, country or region in the world. Given the nature of the subjects described, this chapter is divided into two main areas. The first sections highlight some of the more humanistic aspects of railway stations, while the second part provides a more

[2] Another recent article (Álvarez-Palau et al. 2021) presents some of the other studies that have focused on the railway network in Europe.

technical explanation of how a GIS is constructed, based on work that has already been carried out in Great Britain.

10.2 Station Typology: What Is a Railway Station?

As the organisation of rail transport is complex, there are many different types of station; up to 40 types have been described, with each having a differentiated set of functions. When we talk about a railway station, we normally understand this as including both the main building, or building for passengers, and the group of other buildings and facilities that accompany it (Santos y Ganges 2007: 152). Reality, however, is more complex than this, because there are stations exclusively for travellers, or for freight, mixed-use stations, stations for the sorting and organising of trains, container stations, technical stations and also stopping points, sidings and loading bays. This shows the complexity inherent in the term "railway station". In this chapter, we shall exclusively study stations that are characterised by facilitating access to, and from, trains for people and goods.

The railway station is an essential point of transfer but one that can never perform the function of providing door-to-door delivery. In this sense, Hilberseimer (1927) understood the railway station as being a "traffic transformer"; he saw it as a connection point, located in an architectural environment, which brings together two very different types of traffic: rail and road transport. He saw its function as being that of organising this minimal intermodal connection and, in the best of cases, also combining this with access to other means of public and private transport.

Wherever it is located, the railway station is a point of reference: both for the traveller who arrives in the city and also for users who are going to the train. In this sense, for railway companies, it constitutes a prestigious asset, especially in the case of stations located in the largest cities. Its architecture should therefore make it a recognisable point of reference for the public and a catalyst for new technologies.

Within the context of this book on historical GIS, railway stations interest us in terms of the evolution of their location within their immediate territories. Their organisation via a spatial database makes it possible to analyse the importance of their function and the impact that they have on phenomena such as population dynamics, the built environment and the economic activity of their immediate territories. As we shall see in this chapter, to carry out such an analysis, it is necessary to organise a GIS map structured in different layers and for different periods that permits quantitative analysis. However, at the same time, we should not forget to underline that the study of railway stations will also have an inevitable qualitative dimension. With this in mind, in the following section, we have highlighted its inclusion in the field of qualitative studies and, in particular, within the framework of the digital humanities.

10.3 The Context of the Study of Railway Stations: From Digital Humanities to Analytical Studies

Given their architectural significance, it is not only railway machinery but also railway stations that form part of the history of heritage and technology. One area in which this content has been valued and contextualised is that of digital humanities (DH), which cover a very wide range of themes and approaches. DH have developed enormously, thanks to their capacity to circulate content in a digital format and for didactic purposes. When this content can be located in space, its elements fit in perfectly within the scope of H-GIS. This publication cannot examine these questions in much detail; the subject matter of the majority of its chapters involves a more specific subtopic: spatial history, which is developed under the umbrella of DH research. Its objective is to broaden the traditional historical narrative by incorporating sources in digital format and using them to examine new interpretations. One example of this line of research involves a specific technique that we have used. This involves applying data mining techniques to digitalised collections of books and newspapers; in some cases, there is suitable material of this kind available as early as the nineteenth century. The automated treatment of these texts allows us to work with a broad range of information that can then be exported to databases.

Numerous publications provide a general overview of the themes that have been treated by H-GIS (Bodenhamer and Gregory 2011) within the field of DH. Parallel contributions have also been made in the fields of railway and urban history (Schwartz et al. 2011; Gregory and Marti-Henneberg 2010). However, the theme proposed here, which primordially centres on railway stations, is one that has not yet been fully incorporated into studies of railway history involving H-GIS. The following paragraphs are dedicated to explaining our study objective within the field of analytical studies of railway and urban history.

In this line, there have been significant advances in the identification of patterns relating to the impact of railways on population and economic activity in Europe. This vision has examined both the whole continent (Martí-Henneberg 2013; Álvarez-Palau et al. 2021; Capel 2007) and also specific countries and areas, such as the Nordic countries (Enflo et al. 2018), Balkans (Stanev et al. 2017) and Spain (Esteban-Oliver and Martí-Henneberg 2022). This analysis of the impact of the railway has not only been limited to the past but can also cover the period up to the present day; it therefore also fits in with the debate associated with the recent upsurge in rail transport. With this in mind, it is relevant to make a final reference to the arrival of railway stations that serve HST services and to the controversy associated with their functionality (Solanas et al. 2015). It is relevant to note that the current layout of the HST network is causing similar controversies to those that arose in the nineteenth century and that were related to the central or peripheral location of railway stations in the cities that they connect.

There are also others who have analysed the economic (Herranz 2007), urbanistic (Capel 2011; Oliveira 2013), environmental and social impacts of railways (Bowie 1996; Sauget 2005; Purcar 2021). In these fields, railway stations have also merited very little attention in the majority of countries.[3] In certain cases, we have specific, yet very relevant, information that serves us as a point of reference. For example, an exhibition held by the Pompidou Centre in Paris, in 1978 ("Le Temps des Gares", Dethier 1978), studied and profusely illustrated the artistic and conceptual features that are associated with the relationship between railways and stations in different societies and cultures. Even so, only one of its sections referred to how stations have conditioned urban planning and the expansion of cities. Furthermore, at no moment in that major exhibition did anyone consider how railway stations had transformed their environment in any other ways: economic activities, urban morphology or complementary means of transports; this is something that we propose to investigate. However, before going into these more specific aspects, we shall dedicate the next section to highlighting the presence of the railway stations in art and, more specifically, the role of the station as a symbolic element and a point of reference.

10.4 Railways and Railway Stations in Art

Both the railway stations and rail travel have been attributed a symbolism which has largely been associated with farewells, re-encounters and the dream of travelling. The railway station has been its main stage and has, almost inevitably, been associated with artistic production in a number of different fields. The first of these is literature, in which it has been treated as a source of urban knowledge, in numerous studies (Alves and Queiroz 2013). The relationship between railways and the writers of several different times is a theme that has been specifically studied (Ponce 1996; Powell 2017). It has been very much present in literature, but more at a symbolic than a descriptive level. Amongst many examples, it is possible to highlight the novel *Anna Karenina*, in which the main protagonist meets her lover on a train. Then, after numerous problems and much soul-searching, Ana finally decides to put an end to her life by throwing herself onto the rails. In Spanish literature, there have also been several examples of literature incorporating the subject of the railway, as in the novel *Nada*, by Carmen Laforet, which begins at the Francia railway station in Barcelona, where the main protagonist first arrives in the city, looking to start a new life. In other languages, there has also been an important presence of railways in literature. We can cite two well-known examples amongst many others. The first is *Tess of the d'Urbervilles*, by Thomas Hardy (which was made into a film by Roman Polansky), in which the train appears as an innovative agent that makes it possible to sell milk to the city. Similarly, in the *Count of Montecristo*, by Alexandre Dumas, the train and the telegraph system play a fundamental role in the story, being instruments that the Count uses to exact his revenge. In short, the railway station became a protagonist as a symbolic element of change and internal transformation, whether associated with someone arriving and something new beginning or escape from a previous life. Literature is not only a source that allows us to access detailed descriptions of areas around stations, but their presence in novels also shows an interest in them on the part of authors and readers alike. This is an interest that has not diminished over time, judging from the continued presence of railway themes in modern novels, such as *The Girl on the Train* by Paula Hawkins (2015), to cite just one recent publishing and cinema success. The interest of today's society in railways and related issues continues to be very real and present.

Painting is another area to take into account. Claude Monet's predilection for the Saint-Lazare railway station in Paris is well known. In Spain, Darío de Regoyos has also produced many railway-related paintings (including *El tren que pasa*, 1901, and *El paso del tren*, 1902, amongst others), but in his case, the theme is mainly rural, contrasting the arrival of the train with traditional ways of life. Whatever the case, paintings dedicated to the areas immediately surrounding railway stations tend to be rare.

Examples of railway stations in photography and in cinema are much more abundant. The first film to be made captured a train entering "*La Ciotat*" station, in the south of France.[4]

These examples have been highlighted to show the many and varied forms of intellectual stimuli associated with the train. In the next section, we highlight the potential of H-GIS for organising and analysing information related to the development of rail travel in one specific city: Barcelona. This example is used to show one way of conducting this

[3] In Spain, the exception to the rule has been the line of work followed by a group working with Professor Demetrio Ribes, at the Universidad de Valencia (Aguilar 1988).

[4] https://www.youtube.com/watch?v=v6i3uccnZhQ

type of monographic work; it has been conceived with the aim of providing a model that could serve for any similar case study.

10.5 The Case of Barcelona

The introduction of railway stations in cities marked a before and after in urban morphology and ways of life. Each station implied a revolution for the labour market, economic expectations and society in general, in Europe in the mid-nineteenth century. All the main cities already had rail connections by around 1850, while most medium-sized cities gained rail access shortly after. It is possible to affirm that by the middle of the nineteenth century, the railway was the main agent of urban transformation in Europe. Although there were certain common characteristics, each case, city, station, and station area had its own specific features.

The most important general characteristics related to a variety of different features. Firstly, from a chronological perspective, the initial stage of railway fervour, in the planning and establishment of railway projects, took place in Western Europe in the 1840s and 1850s. The connecting of cities to this new network mainly took place through stations that were inserted into empty spaces near urban nuclei. This caused debate, in each case, over the best way to connect the city to the railway station. Three main actors were involved in this planning process: the railway companies, the Ministry of Public Works and the City Council. Most of the cities involved maintained their mediaeval walls and the original morphologies of their urban enclosures, with this generating a debate concerning how to include the railway in their plans for urban expansion.

The casuistry involved was particularly complex in the case of cities that were to serve as nodes of communication. These had to integrate various axes of communication, which often belonged to different railway companies. This was particularly evident in capital cities, like London and Paris, but it also applied to others, such as Barcelona. In this way, each of the urban stations provided a relevant connection with the exterior, although there was no central station that provided a structure for the wider whole. This dispersion posed the problem of how best to connect different stations so as to achieve efficient logistical solutions for the transportation of merchandise over long distances and for passenger transfers.

The city of Barcelona provides a relevant case study for a number of reasons, but it is possible to highlight two in particular: the existence of a proliferation of very different railway stations and their arrival coinciding with an urban planning experiment of the highest order, the urban expansion plan of Ildefonso Cerdá (1815–1876). Regarding the presence of different types of station, it should be noted that the territory of Barcelona already had nine railway stations in 1875, with four of these being at the end of lines. These four stations corresponded to different business initiatives, within what was a particularly dynamic context, which were driven by industrial and financial interests. The lengths of these lines were gradually extended, which turned these stations into connection terminals not only for short but also for long-distance transport. Barcelona was also the area of action of one of the founders of urban planning: Ildefonso Cerdá. Cerdá applied his ideas – which were expressed in a general theory of urbanisation – not only to Barcelona but also to the neighbouring municipalities. His plan was the product of two different elements: an intense theoretical reflection on how the cities of the future should be planned and an empirical study of the living and hygiene conditions of Barcelona (Cerdá 1867, edited also in 2022). The railway was always very present in Cerdá's conception of the city, both in terms of its use for internal transport and its external connections. There was a generally held belief at the time, which was particularly popular amongst civil engineers that the railway was about to change society, the economy and, as a result, urban planning.

Cerdá had a revelation about this during a visit to France when he was young. It was there that, for the first time, he saw a railway train in service, at the station of Nimes, which transported about 500 people. For Cerdá, this was like seeing a city in movement, and the experience convinced him of both the transformative power of the railway and of the need to integrate it into the new urban planning, in which urban morphology and movement were to be two inseparable elements. As a result, he planned a city in the form of a game board, whose streets, which were to run in parallel and diagonally, where to facilitate transport. In this way, Cerdá thought that it would be possible to combine various urban functions, residences, areas of production, services and leisure, in a complex urban tapestry, without the need to create any specialised units. Achieving such an integration of activities was the essence of Cerdá's project, but to achieve this, it was necessary to ensure free and dynamic flows. In fact, until recently, the Ensanche neighbourhood of Barcelona has had a dense industrial infrastructure (Tatjer 2018), combined with artisanal, commercial and wholesale establishments. To give adequate functionality to this wider whole, it was essential to have a fluid transport system, and this, according to the 1859 project, was to be based on rail transport. To facilitate 90° turns of mobile material, blocks of houses had to have a chamfer shape (Fig. 10.1[5]). The train was not, however, to be the main protagonist for intra-urban transport; this was to be dominated by the tram and later by underground train and bus services. What was largely constructed, and has stood

[5]It shows part of the Léon Jaussely (1875–1932) Plan, a French urbanist. His solution for the 90° turns was inspired by Cerdá.

Fig. 10.1 Preliminary project of links of the city of Barcelona. Plan number 9. Trams and railways. (Source: Jaussely (1904))

the test of time, was a plan to facilitate railway connection with the exterior. Here, Cerdá had basically three priorities: the port, providing a large freight station (at El Poblenou, to the north-east of the city) and establishing interconnections between the main stations and with external nuclei in other municipalities (Fig. 10.2).

However, the 1859 project found part of the railway network that had already been constructed, on centrally located land that was of strategic importance for the future of the city. The challenge posed was therefore that of how to integrate what had already been constructed into a game board scheme that could only allow relatively minor adaptations. It is also important to consider that the actors involved in this process, the military establishment, the Ministry of Public Works, Barcelona City Council, associations of land owners and railway companies, were often at loggerheads. In Fig. 10.3, it is possible to observe the juxtaposition of the existing railway reality and the new project, with its game board layout, including a few diagonal roads, which – in part – integrated railway lines that were already in service. At this point, it must be stressed that, according to Cerdá, the geographic orientation of the previously mentioned game board layout had to be approved for a fundamental reason: the need for all the flats to receive at least a minimum number of hours of direct sunlight every day. This explains the rotation of buildings in relation to the sun's rays which predominantly come from the south. The layout was designed so that all the flats not only looked onto a street but also onto an interior patio.

Taking these principles into consideration, Fig. 10.3 shows the existing stretches of railway track, which were contemplated in the Cerdá project. It also shows those foreseen for the future, which should be compared with those which were actually built after Cerdá's death. In this plan for rail connections, it is important to highlight the longitudinal connection with the port, the interconnection of all the main railway stations and the creation of a railway pole in the industrial area of El Poblenou.

We shall now return to the analytical theme and explain how the GIS for railway stations in Great Britain was con-

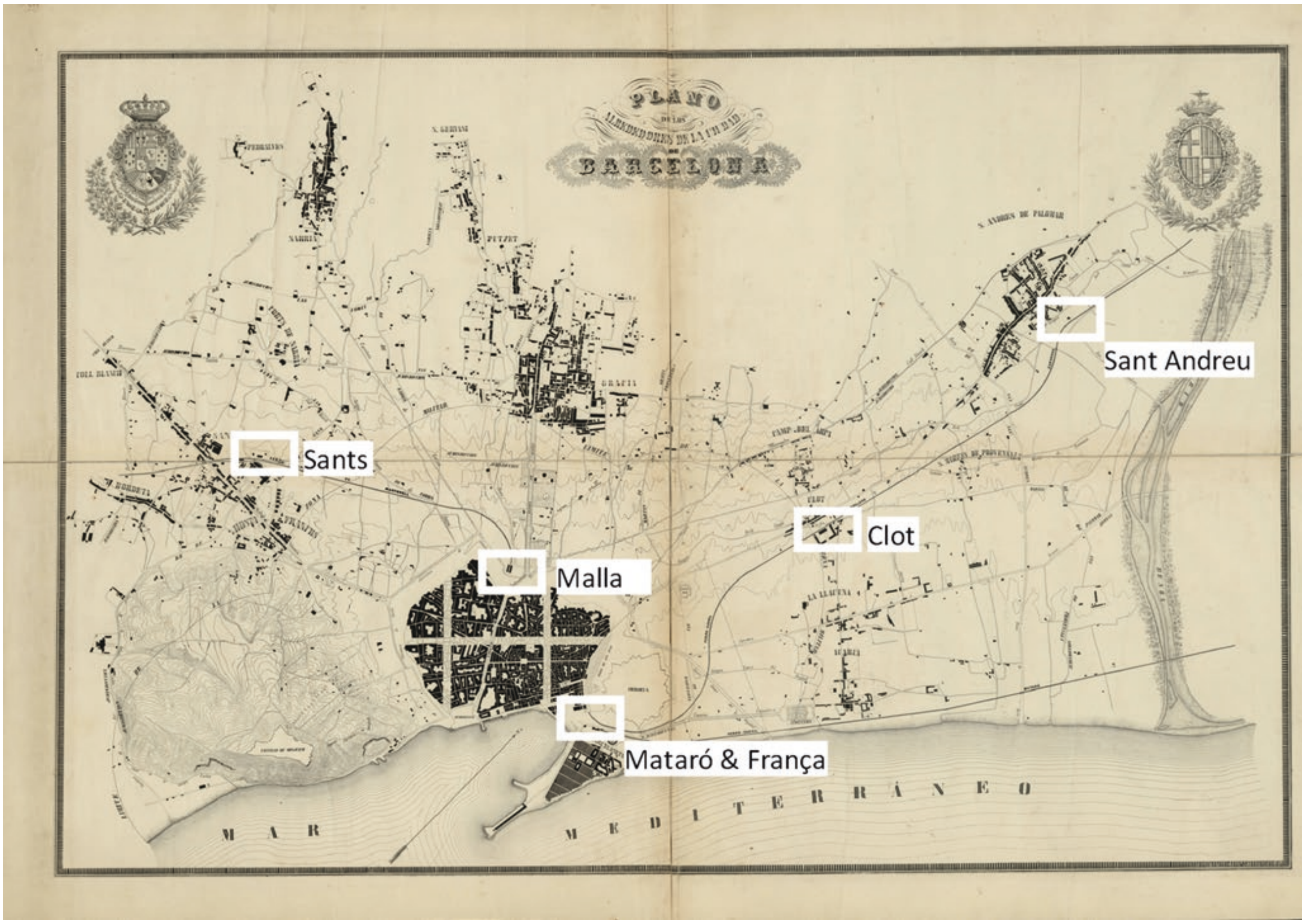

Fig. 10.2 Map of the surroundings of the city of Barcelona. (Source: Cerdá (1855))

structed. This explanation has been conceived in such a way as to serve as a reference for similar projects in other countries.

10.6 The GIS of British Railway Stations

Our study of the evolution and impact of the railway network in the United Kingdom (Alvarez-Palau and Martí-Henneberg 2018) used a single source for the reconstruction of its cartography. This was the meticulous work carried out by Dr. Cobb (2003), which he published as an atlas. The first phase of our work consisted of giving priority to vectorising and introducing the data that interested us: the years in which all the railway stations and stretches of track in the United Kingdom opened and/or were closed. In the future, it should be possible to further enrich this database by incorporating information about broad gauge track, electrification, the companies that participated in the construction process and the average number and speed of both the passenger and freight services, amongst other themes.

The database that we originally created in GIS format included *6550 lines* and *8475 stations* and covered the territory of England, Wales and Scotland. We also included all of the end-of-line junctions and those at which two or more lines met (middle junctions), both of which will be very useful for future analysis.

The basic attributes of the *lines and stations* were:

RW_OPEN: Year of opening during the period studied, 1807–1994
RW_CLOSE: Year of closing
ST_OPEN: Year of first opening
ST_CLOSE: Closure year

10.6.1 Process of Developing the GIS

This is an H-GIS of railway lines and stations in Great Britain between 1807 and 1994.[6] It has been possible to obtain the

[6]Web https://europa.udl.cat

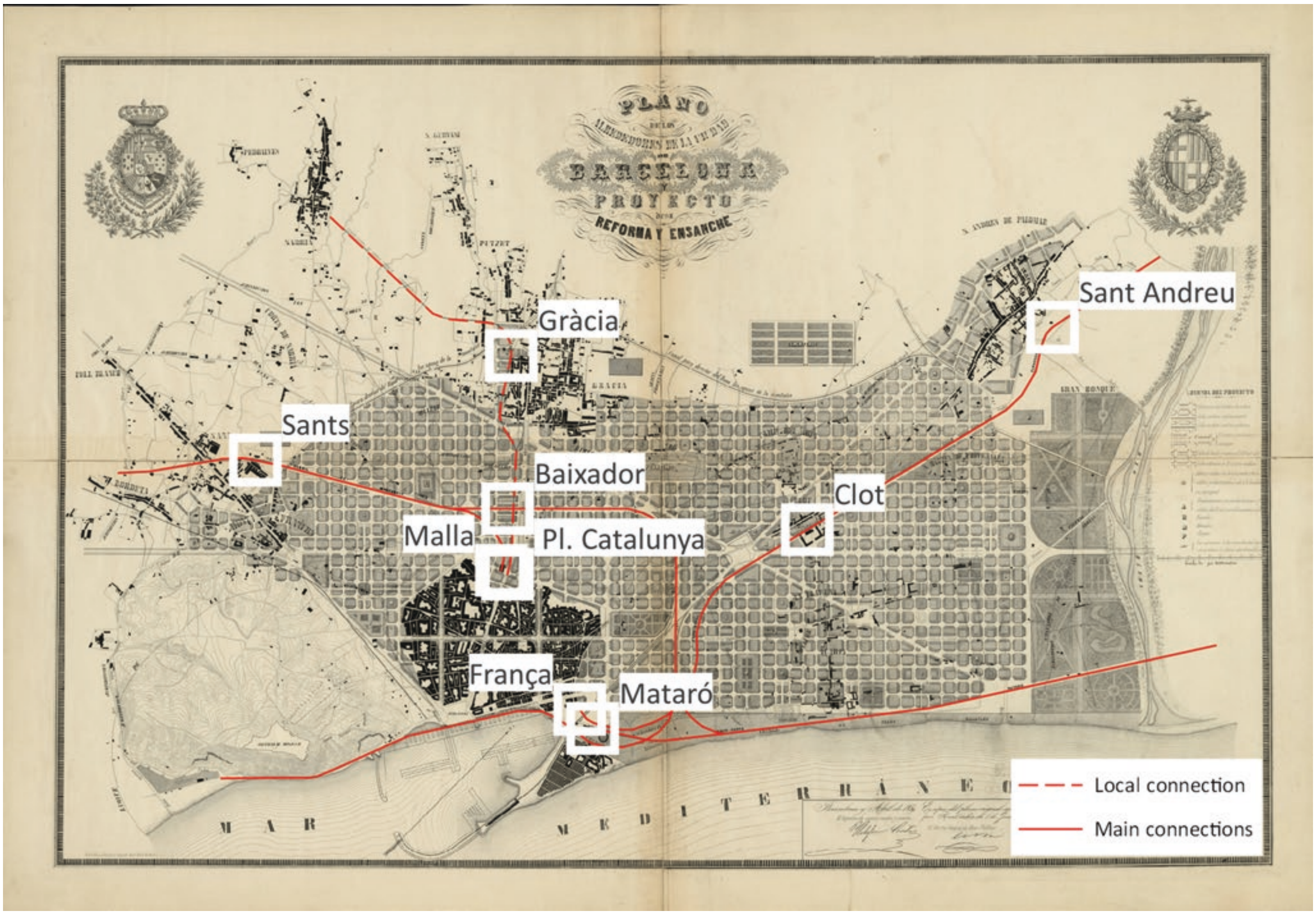

Fig. 10.3 Cerdá project. (Source: Cerdá (1859))

year-to-year details of this information, thanks to the Cobb Atlas. Below, we shall outline the process followed to create the GIS, which ranged from georeferencing the pages of Cobb's book to validating both the graphic elements and the alphanumeric attributes.

10.6.1.1 Georeferencing

Cobb's work consisted of 646 pages, on paper. These were also made available in 333 raster images in digital format, thanks to permission from Colonel Cobb and the publisher. The result was a mosaic of images that covered our study area.

As these were flat images, without any deformations, the georeferencing did not generate any noticeable RMS (root mean square) values. The process of digitising the railway tracks took approximately 2 years to complete and was carried out by various members of our team. Any errors were manually corrected during the validation process. Having reached this point, we were satisfied that we had completed the first phase of our work.

10.6.1.2 Validation

Given the circumstances explained in the previous point, we were concerned about the accuracy of the information contained in the database. We were concerned as to whether it was complete (in other words, whether all the lines collected by Cobb had been digitised) and as to whether the content was coherent; in other words, we were concerned as to whether the attributes of the lines referring to the years of opening and closure were the ones that Cobb had listed in his book. The possibility of making errors during the digitalisation process remained high, despite the use of good practices and the interest shown by those carrying out this task. The database already contained more than 10,000 lines, with their respective attributes. In such cases, the possibility of revising all of the lines does not tend to offer a good solution as it supposes investing an excessively large amount of time in a manual process that cannot guarantee that it will eradicate all of the possible errors.

Railway stations were then added to the lines. Their validation was exhaustive, as they had to be used to validate the railway lines. Furthermore, the tremendous wealth that the stations contributed to the analytical potential of the GIS also led us to incorporate them in all of their different modalities.

In the case of railway stations, their validation and the correction of errors were carried out manually. To facilitate this work, a simple application was developed in ArcObjects which made it possible to select, visualise and edit the station attributes from a single graphic interface. The first step consisted of carrying out a visual check, station by station, to make sure that the attribute in the TYPE field corresponds to Cobb's symbology. In the second phase, based on the station point, we checked the fields containing the dates of opening and closure, based on the following unfilled reference grill.

TYPE	ST_OPEN	ST_CLOSE	ST_OPEN2	ST_CLOSE2
O' OR 'OC'	<>0	0	0	0
		<>0	<>0	0
T' OR 'TC'	<>0	<>0	0	0
			<>0	<>0

When validating the dates of lines opening and closing, based on those of the stations, this was done automatically, using a Python script, and based on track intersections, with these having been previously merged based on the fields relating to their years of opening and closure and those of the stations.

At the same time, we also checked the coherence and accuracy of the results based on the following, very evident, considerations:

– It was not possible for any of the stations to have been opened when its lines were closed.
– It was not possible for a station to close after the closure of its line.

In summary: the life of a station must, at the very least, correspond to the lifetime of one or more lines. This internal coherence in the data allowed us to correct many date attributes relating to lines which may not otherwise have been identified.

An example of validation based on the year of opening (errors in red) (the following tables are too big): The followin two figures/tables are too large

RW=1800	RW=1900	RW=1800
ST=1800	ST=1800	ST=1900

Example of validation based on the year of closure (errors in red).

RW=0	RW<>0	RW=0	RW=1900	RW=1800
ST=0	ST=0	ST=1900	ST=1800	ST=1900

After this validation, we created a typology of the line layer and the station layer, which would check that there were no stations without connections or superimposed lines.

Once the errors that were detected had been corrected, we revised all of the stretches of track that were less than 100 m long, eliminating any residual microsegments and joining together the main lines, thereby leaving only a few tunnels of less than this length on the line layer.

The connected stretches were merged and given identical opening and closure dates. As a result, the number of registers was reduced by 35%, leaving the line database cleaner and more coherent.

Next, we automatically obtained (through the creation of a *geometric network*) all of the end-of-line junctions for each stretch of track that did not coincide with the stations, and we identified the junctions that corresponded to ends of lines.

Using the application developed in ArcObjects, the end-of-line junctions were checked, one by one, to see whether there were any that had been digitised without their corresponding stations. This process was relevant because end-of-line stations are important for studying the evolution of accessibility.

The final stage of the validation process involved using a tool constructed from a model that included various processes and used lines, end-of-line junctions and stations. The objective of this tool was to show the network in a given year and to automatically generate intermediate middle junctions so that the technician carrying out the validation could detect any possible errors in the date attributes of the lines by checking the coherence of their connectivity. At the same time, the middle *junction* layer was automatically generated, in a controlled way, to provide year-to-year data.

Below, we provide some of the analytical results for the whole network and its stations which were obtained using this GIS.

10.6.2 Results of the Evolutionary Analysis of the UK Network

The map series presented here allows us to accurately observe the development of the British rail network. The process of expansion is equally as significant as that of its subsequent contraction, from the 1950s onwards. The series can be studied on a year-by-year basis or by observations made at 10-year intervals. In summary, it allows us to obtain a view of the railway network for any year that is required. Given its versatility and precision, it is better than any of the other documents currently available on this subject.

This GIS of British railways is an instrument for analysis which will make it possible to carry out territorial and socio-economic analyses that go beyond the limits of this chapter. We would like to underline, however, that this case study will be the subject of research into the coherence of the railway network, both in itself and in relation to the territory in which it is located. It has also been possible to analyse its causal relationship with patterns of population distribution, and in the future, it will also be used to examine those of the working population, which will be broken down into different employment sectors (Bogart et al. 2022). A previous, and more general, presentation of this material suggested that there were three major periods of infrastructure construction. From 1830 to 1910, there was a sustained increase in the size of the network, which was paralleled by an increase in the number of railway stations. The next 40 years (1910–1950) were characterised by a period of stability, which ended with a crisis in 1950. However, the 1960s saw a radical restructuring of the railway network, which was even more striking in terms of the reduction of the number of stations in service. The reason for this was that priority was given to the speed of railway services over the connectivity of the network. The most extreme situation, in this respect, related to the provision of HST services, for which the average distance between stations was around 100 km. Whatever the case, the design of the network did not subsequently undergo any more major changes, with it largely maintaining a similar total length of track to back in the 1860s. Its structure, however, had little in common with that of the previous century; this was largely due to major changes in the distribution of population resulting from changes in the location of its users.

In the four maps in Fig. 10.4, it is possible to observe the great landmarks in the design of the British railway network. The period of expansion was equally as significant as that of closures. In the first of these periods, private investors (taking advantage of state concessions) gave priority to opportunities to do business, providing connections between cities and access to ports and mining areas. They also provided connections to large rural areas, at a time when the train had little competition. However, the emergence of road transport, in the middle of the twentieth century, led British Rail, making rapid, and quite drastic, adjustments.

The following figures[7] show two relevant factors in greater detail: the combined evolution of the rail network and its stations (Fig. 10.5); and the cumulative process of line construction and closure within the network. Figure 10.6 shows the total number of kilometres of railway track and the number of stations in service in Great Britain during the period covered by the Cobb Atlas (1811–1994). It is possible to observe that after the initial period of expansion, the network entered a period of stability; this was followed by one of intense decline, from 1950 onwards (also see the map for 1970 in Fig. 10.4) and then later, a period of stability. Since 1970, the total length of track (km) has remained roughly the same as today. It is also possible to observe that the number of stations in the network followed a parallel evolution to the increase and decrease in the total number of kilometres of railway track; it is not so evident as to why that should have been the case. In other countries, such as Finland, it has been observed (Alvarez-Palau and Martí-Henneberg 2020) that the process of line closure, which was also associated with the rise in motor vehicle transport, implied a process of station closure that also affected lines still in service. As a result, in the case of Finland, it is possible to observe a relatively greater decrease in the number of railway stations. Finally, Fig. 10.6 compares the intensity of the periods of maximum change, in terms of both network expansion and line closure. The relevant difference is that while the expansion phase took place between 1840 and 1880, the process of line closure was much faster, taking place almost entirely in the 1960s. This was the difference between an expansive dynamic, which involved several different companies and was highly complex, and line closure due to a political decision, which it was possible to carry out much more quickly.

In the next section, we shall refer to exercises relating to the case of Spain.

10.7 Tutorial: The Use of Stations in Quantitative Studies

The content explained in this chapter shows the relevance of studies of the location of stations within a given country or region in order to analyse its socioeconomic transformations in territorial terms. In the following sections, we shall concentrate on providing specific examples on the use of a historic GIS of railway stations and on how these can be used to calculate the impact that they have had on the establishment of centres of population and economic activities.

We start, here, with the supposition that transport infrastructure is one of the most relevant factors for explaining these processes, given that, in the nineteenth century, the railway transformed accessibility to the territories to which it provided service. This type of study has made it possible to verify the increase in the rhythm of urbanisation (Gregory and Martí-Henneberg 2010. Atack et al. 2010), in the general growth of population (Büchel and Kyburz 2020) and in the contribution of industry to employment (Bogart et al. 2017),[8] within the areas of influence of railway stations.

[7] Check all this material at our website: http://europa.udl.cat/projects/british-railways/.

[8] When we try to quantify the influence of the railway on a territory, we must take into account the possibility that the dynamism of the municipalities in the pre-railway period could have conditioned the trajectory of the network. This would imply a certain element of selection bias. To control for this possibility, the most common approach to use is an instrumental variable (VI) strategy (Banerjee et al. 2021; Büchel and Kyburz 2020, Esteban-Oliver 2021).

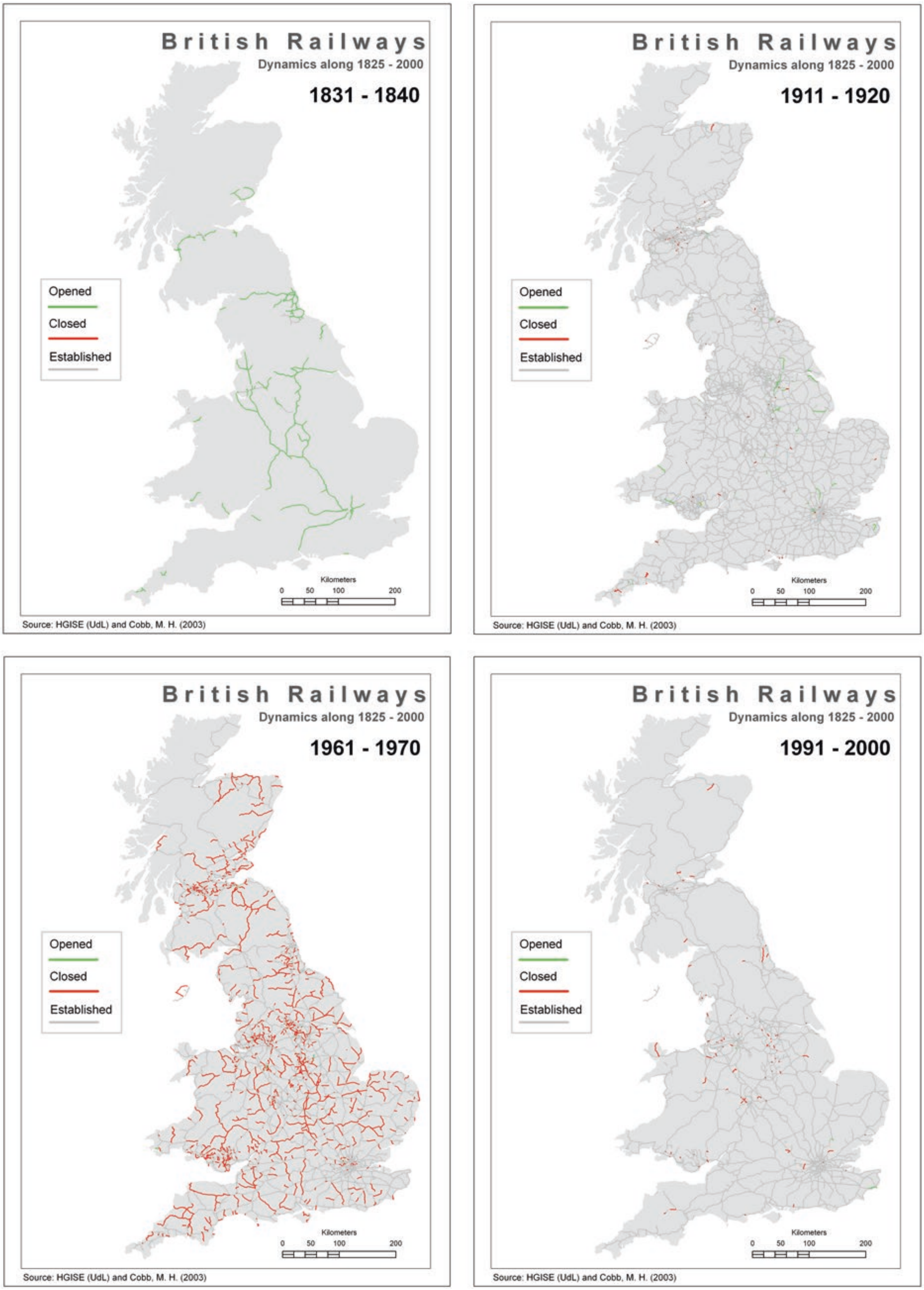

Fig. 10.4 Evolution of the UK rail network

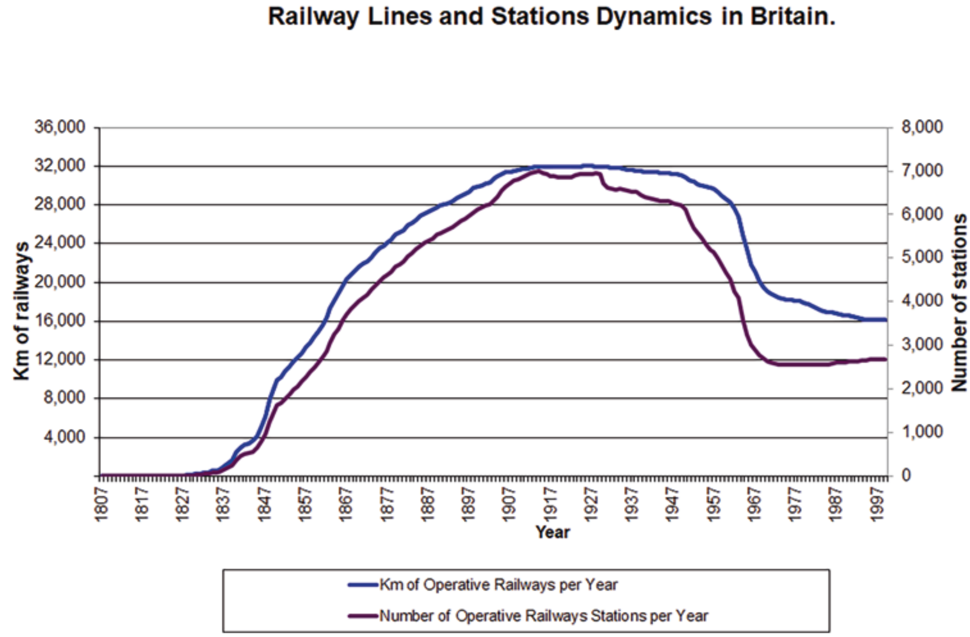

Fig. 10.5 Km of tracks and the number of stations, Britain 1810–1994

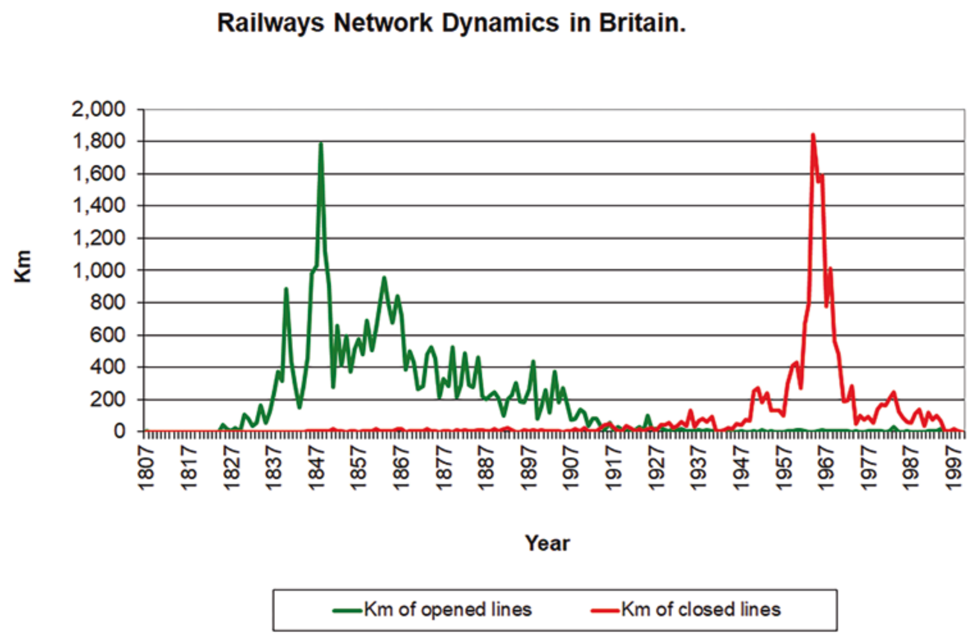

Fig. 10.6 Evolution of rail openings and closures in Km, Britain 1810–1994

To quantify this type of railway effect, it is necessary to use databases that are compatible with SIG and which include the exact locations of infrastructure and transport (Martí-Henneberg 2011; Atack 2013). Only in this way is it possible to correctly identify what is the main explanatory variable in these studies (*access to the network*). To measure this effect, it is possible to use one of three approaches: to determine whether a line crosses a municipality; the distance from the centre of each municipality to the nearest line; or the distance from the centre of the municipality to the nearest station or stopping point.[9] In this chapter, we shall focus on developing the *access variable* using the last of the suggested approaches, as this is the one that provides the greatest precession of analysis. For this reason, in Exercise 1, we propose (1) how to reconstruct a network of stations and their attributes and (2) how to associate it with the territory via the *access variable.*

[9]Each of these approaches has its advantages and inconveniences. The most relevant of these are explained in Chap. 2 of Esteban-Oliver (2021) and in Mimeur et al. (2018).

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Mapping Half a Century of Accessibility via the French Railway Network, 1860–1910

11

Thomas Thévenin and Christophe Mimeur

Abstract

In 1930, the French railway network consisted of more than 50,000 km of lines. Less than a century later, the network has been halved to 28,000 km. This phenomenon of the extension and then retraction of railway lines has not only shaped the landscape, but it has undoubtedly had an even greater impact on the political, economic and demographic organisation of the French metropolitan area. Beyond these structural effects, our relationship with time has been profoundly modified. Based on this observation, the chapter proposes to revisit these major transformations in the light of the concept of accessibility over a long period of time, from the construction of the railway network to its apogee in 1930.

To this end, we will first present in detail the French database, which will be the support of our method. Integrated into a historical GIS, this numerical corpus lists the openings, closing and modernisations of railway lines of national, regional and local interest in France. Two dynamics of networks will be combined in this case: the topology of the network and the revolution of speed, which produced many disparities from one line to another. A demographic database completes this first source to reveal the spatial dynamics. We will also see how to transform this geographical network into a graph capable of assessing travel times over a century and combining railroads and pedestrian networks, very useful in the nineteenth century. Furthermore, the results will be presented in the form of unipolar and multipolar accessibility maps, in order to relate effects on demographic changes. This case uses free software, from the acquisition of spatial data towards H-GIS and graph calculations.

Mentioned also are the didactics, how users will be able to work on this subject, using the data provided or other data for other periods or countries.

During this chapter, all the database and software will be available in open access. The French dataset will be available in free access as a multigraph composed on lines (arcs) and stations (nodes). The municipal population will be made accessible for each decade, during the entire study period (1830–1930) in the form of a shapefile. A free GIS (QGIS) will be used to visualise and map the data. The accessibility calculation will be provided with the help of the free software (Modaccess) developed in the TheMA laboratory. Then, users will be trained to use QGIS to formulate indices in the form of SQL queries. Finally, accessibility maps will also be produced using QGIS.

Keywords

France · Rail network · Accessibility · Nineteenth to twentieth centuries

11.1 Introduction

Infrastructure that enables circulation between points and along lines is commonly said to 'form a network'. But early networks did not necessarily begin life as networks: the earliest water supply networks in Europe and North America started out as separate aqueducts (Barraqué 2014). The Roman road network facilitated troop movements but was not initially designed to connect the whole of the empire from West to East. It was simply that the growing number of

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links meant separate itineraries became joined up, and soon all points were interconnected. The infrastructure of such overland networks and especially transport networks was lastingly etched in space. Yet over time, networks are also subject to innovation. While the infrastructure extends in space and over time, its characteristics alter the conditions of movement over the network. Many of the social sciences enquire into the role of networks in economic growth (Fishlow 1965), regional development (Rietveld 1989) or urban growth (Duranton and Turner 2012). Scientists assumed from early on that there was no automatic network effect, and they aimed to identify complex interactions between space and network. To achieve this objective, they had to multiply studies over space and time. Present-day methodologies use historical trends as instrumental variables to take into account the necessary endogeneity between space and network and to renew approaches by economic historians or historical geographers. But this kind of approach requires geo-historical data, which often prove unreliable and disparate. This chapter aims to provide a generic method for assessing accessibility over time, involving multiple modes of transport, and drawing on both theoretical and empirical data.

11.2 Characterising Networks Over the Long Run: A Variety of Approaches

Characterising the space-time evolution of networks over the long term is a central topic for many disciplines. A brief review of the state of the art shows a horseshoe-shaped curve (Fig. 11.1). The Y axis contrasts the experimental sciences with the humanities and social sciences. On the X axis, space is originally considered as a homogeneous surface with no physical or human constraints. This is isotropic space. Under the influence of the social sciences, anisotropic space (subject to topographical constraints and human occupation) is gradually gaining ground in research. The purpose of this second section is to trace this major development through different approaches adopted in the last 60 years.

11.2.1 The Isotropic View of Space in Mathematics and Economics: 1960–1970

As early as 1960, a pioneering team of geographers and mathematicians used the formalism of graphs to characterise the topological properties of the US interstate highway network. Topological properties were used to simulate the growth of the network by connecting the largest city at each iteration (Garrison 1960). Ten years later, Black demonstrated that the centre/periphery model existed before the construction of the rail network in Maine, USA. To this end, Black (Black 1971) calculated potential accessibility based on mid-twentieth-century populations. The result could be read as a network structured to form a hierarchical tree. These experiments remained discreet or even 'dormant' (Xie and Levinson 2009) because they were constrained by limited computing capacity.

From the 1970s, economic approaches focused first on questions of infrastructure design. To this end, modelling work was developed that integrated congestion and road capacity issues. This was the golden age of the four-stage models (Ben-Akiva et al. 1997) and later of the LUTI models (De la Barra 1989). More recently, regional science and economic history have focused on studying the extension of networks over time. Atack et al. (2010) identify macroeconomic effects between the growth of a transport network and regional development based on the construction of new infrastructure. More recently still, Hornung (2015) has attempted to identify microeconomic effects of the arrival of a new network in the demographic growth of cities, thanks to the increasing use of geographic information systems (Kasraian et al. 2016). These tools use econometric modelling to compare linear or point variables of the network with linear or zonal variables.

11.2.2 The Anisotropic View of Space in Regional Studies and Experimental Sciences: 1980–2020

The advent of behavioural studies in the 1970s profoundly challenged economic approaches based on the notion of *homo economicus*. The representation of average behaviour in an anisotropic space leads models to mask the diversity of travel patterns and unequal access to resources. In this context, regional science has been working on integrating the time dimension into the estimation of transport costs. This new approach arose out of time geography initiated by the Swede Torsten Hagerstrand in the 1970s (Hagerstrand 1970) and was then extended in the work at the Transport Studies Unit in Oxford in the 1980s (Jones 1983). Economists have also taken the measure of the phenomenon by explicitly integrating the temporal dimension into choice models applied to transport modes. These approaches were honoured by the Nobel Prize in Economics awarded to Heckman and McFadden in 2000 (McFadden 2001). Thus, in addition to topological measurements, accessibility measurements have been developed. Since Hansen's seminal work (1959), this concept has continued to evolve (Hansen 1959). Initially defined in terms of opportunities for potential interaction, accessibility has been broadened by explicitly integrating the notion of effort. M.P. Kwan (2000) defines accessibility as a

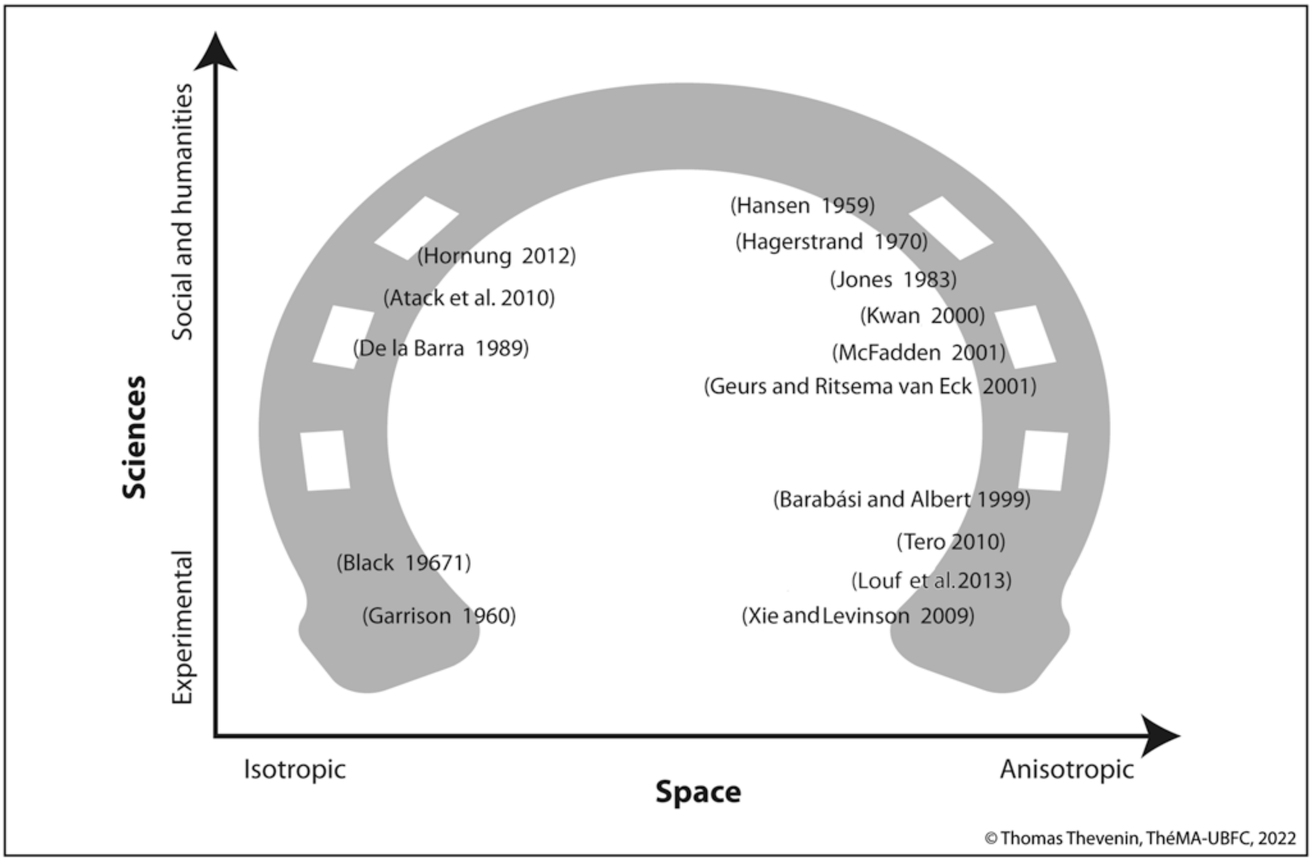


Fig. 11.1 State of the art of network studies over the long run

concept that aims to 'account for the possibility and the effort to travel through space in order to reach a place, a resource or a facility' (Kwan 2000). This structural view of accessibility needs to be complemented by a functional view (Geurs and Ritsema von Eck 2001): 'A measure of the transport system that enables a person or a good to reach an activity or destination by means of a mode or combination of modes of transport'. We propose to combine these two definitions in our geo-historical approach.

The study of networks over the long term has developed from the experimental sciences in recent years: 'traditionally, physicists have modelled the dynamics of a transport network as an optimisation process, with a particular interest in extracting aggregate network characteristics from simple cost functions' (Xie and Levinson 2009). Researchers have identified conserved network properties, regardless of the scale on which they are observed (Barabási and Albert 1999). In another direction, a biomimetic approach revealed similarities between the structure of the Tokyo railway network and a model of organic matter decomposition (Tero 2010). The results of this original study show that the network generated by simulation is very similar to the actual network devised by Japanese engineers. The researchers emphasise the value of using this type of model to design more efficient networks. More recently, certain works have made it possible to combine these approaches with geographers' thoughts on the organisation of spatial networks: 'the majority of existing spatial networks do not seem to be the result of a global optimisation, but rather of the gradual addition of nodes and segments resulting from a local optimisation' (Louf et al. 2013). According to a recent publication, such dismantling of the rail network would not have a negative impact on the performance of the service provided to the population but would instead be beneficial to its overall design.

This review of the literature encourages us not to contrast the approaches but to combine them instead. Thus, our approach needs to combine morphological indicators but also structural and functional accessibility measurements both theoretically and empirically.

11.3 Empirical Testing of Spatial Network Theory

According to Offner (1993), the network can be defined as the medium of exchange and as an instrument of urban and regional planning. The first case refers directly to the interaction between individuals and companies, while the second case refers to the spatial effect. Thus, we assume that the evolution of a transport network interacts with its surrounding space. This assertion derives from the spatial theory of networks developed in France by Gabriel Dupuy in the 1980s. For Dupuy, the analysis of networks is part of a long-term temporality. This scientific posture suggests one should investigate the past, which is necessary for interpreting the present world and its space (Durand-Dastès 1990). This spatial theory of networks is based on the triptych: structure, dynamics and logic.

11.3.1 The Triptych of Spatial Network Theory: Structure, Dynamics, Logic

The structure of a network is defined by its elementary structures. The nodes of the network are the stations, while the lines connect them. The arrangement of locations (Dupuy and Offner 2005) produces an unequal distribution of resources in space. Consequently, these socio-spatial inequalities constrain the network structure. This diversity influences the geometry of the network and complicates the relationships between places. While spatial analysis suggests the use of a topographic metric, the analysis of neighbourhood relations through the geometry of the network requires the adoption of morphological metrics (Barthelemy 2018). The design of the network itself therefore influences the neighbourhood relations and the potential interactions between two places.

The dynamics of a network are defined by 'cycles of development that would show strong times for strong spaces' (Dupuy and Offner 2005) and account for a hierarchy in network performance. In this respect, 'high speeds are only valid for major links, as soon as one leaves the main lines, a clear slowdown takes place' (Studeny 1995). This dynamic is indicative of a disruption of relationships between places and pre-existing patterns. Thus, Riboud declared in 1981: 'it is the journey time that counts and not the distance' (Riboud 1981). Railway innovation in France is therefore made up of ruptures and discontinuities in space, affecting the relative position of places and the interactions they can have.

Logic is a factor specific to the railway network. It is a product of the structure and dynamics of the network. It may be influenced by technical, political, economic and financial considerations, but it may also be conditioned by 'certain laws of network organisation'. The hierarchisation of the network has indeed been observed on several scales. For this, dynamic modelling can be used to analyse the macroscopic and microscopic levels, but it is still rarely used for the long term.

This spatial theory of networks needs to be tested against the reality of the facts or empirical studies over the long term. Taking the example of the growth of the French railway network, the objective here is to show how the evolution of the network intensifies or limits spatial inequalities.

11.3.2 An Empirical Approach Based on Infrastructure

The characterisation of historical networks is often limited to the presence or absence of infrastructure, omitting variations in performance. However, the analysis of a network over time suggests a method for calculating geo-historical accessibility designed to capture the evolution of two main categories of measures. The morphological evolution of the network makes it possible to measure the physical extension of the network over time. The kinetic evolution considers the hierarchical performance of the network in space and time. For this purpose, we adapt the four pillars of accessibility (Morris et al. 1979) to the constraints of the long term:

1. The performance spread of the different transport systems includes major technological developments for speed assessment (electrification, switches, etc.).
2. Consistency with behavioural models is taken into consideration through a bi-modal network. In other words, the rail network is supplemented by a pedestrian network to connect the nearest stations. Thus, different behaviours can be represented.
3. Interpretability is based on the choice of indicators that are comparable, all other things being equal, throughout France.
4. To make the method feasible, all developments are made on open-source software (QGIS) with access to the dataset to facilitate the reproducibility of the methods.

It should be remembered that this work focuses on infrastructure. Consequently, it ignores the diversity of services, such as express trains or omnibus trains, and the frequency or timetables of the trains. Thus, on the basis of the evolution of the infrastructure, we propose to construct indicators to capture this hierarchy, in the structural, dynamic and logical dimensions of the railway network. To do this, one of the main methodological challenges is the availability of data, which is often fragmented or imprecise (Delaplace 2014). The second challenge concerns the structuring of a rich and complex database. In this regard, geo-historical information systems developed over the last 20 years (Gregory and Ell 2007) have taken on a major role in transforming archives into spatialised humanities (Gregory and Geddes 2014).

11.4 The Contribution of H-GIS to the Studies of Historical Networks

The development of spatial humanities contributes to the development of databases capable of integrating spatial and temporal information of a quantitative and qualitative type. This increase in the complexity of datasets requires the construction of research tools that are sufficiently generic to meet the needs of multiple disciplines in the humanities and social sciences. In the field of network analysis, historical GIS took on a central role in the early 2000s.

11.4.1 From H-GIS…

It was not until the early 2000s that the first developments in historical geographical information systems occurred. More than a simple tool for drawing maps and producing them in a chain, the H-GIS is above all a database that integrates the spatial and temporal referencing of entities suitable for geo-historical analysis. The fundamental difference between H-GIS and conventional GIS is the mobilisation of sources that are usually extracted from archival documents and converted into digital form. According to A. Knowles (2005), this alliance of the historical and geographical fields raises conceptual and methodological questions alike. Four recurring problems are regularly recalled in the literature:

- The MAUP (Modifiable Areal Unit Problem) is becoming increasingly important in H-GIS. How can the evolution of the borders of European countries over several centuries be accurately reconstructed?
- Inaccuracy of data: inaccuracy or even gaps are an integral part of historical sources. This discrepancy between the archive and the information system is a real challenge that every H-GIS user must face one day (Knowles 2005).
- The articulation of spatial and temporal scales involves combining the vision of geo-computation, which must transcribe the geographical features of places into coded information, with the vision of the historian, who is committed to providing an anthropocentric interpretation of the transformations of the environment.
- The combination of spatial and temporal analysis in the same protocol.

Despite these many limitations, H-GIS has grown significantly. Archaeology, mediaeval, modern and contemporary history, urban geography, all these related disciplines have contributed to an increase in and diversification of H-GIS projects. We will focus on two main families: GIS linked to administrative networks and GIS tracing engineering networks.

The study of border changes is at the origin of a significant number of national historical geographical information system projects. These actions have four main objectives in common:

- To establish a standard of accuracy for mapping boundaries and related geo-historical data.
- To facilitate the mapping of historical data and manage its abundance by linking the most used sources.
- To correct errors arising from a lack of geographical accuracy.
- To validate and disseminate information.

Databases from national statistics are associated with stage markers of boundary changes, such as general population censuses or agricultural population censuses. During the nineteenth century, most local authorities arranged for statistical data to be collected. The period covered by the national H-GIS begins with the establishment of this resource and continues to the present day. The objectives that motivate these projects are geo-historical, as they seek to shed light on the understanding of the contemporary world based on a systematic mapping of past situations. The pioneering work carried out in Great Britain is a world reference in quantitative geo-history. The GB-HGIS (Great Britain Historical GIS) is probably the earliest of the national historical geographical information systems and was first published in 1998 (Gregory and Southall 1998). Taking into account changes to administrative boundaries was part of the initial specifications. Collected from 1801 onwards at the parish level, for the smallest partition, the information covers a wide range of themes. The classic socio-demographic data (age, sex, population) are supplemented by the provision of medical care, agriculture or the economic situation. In addition to national documents, highly original textual sources have been associated with cartographic holdings, in order to verify the precise dates of border changes.

From 2007 onwards, the Campop centre at the University of Cambridge (Shaw-Taylor and Wrigley 2014) mobilised all its experience on the statistical and family history of the United Kingdom to build a national GIS covering the period 1379–1911 on a wide variety of topics: population, economy, society, transport, etc. This experience has since been imitated around the world. For example, 2000 years of Chinese history have been retraced in the China Historical GIS (Bol and Ge 2005). The aim of this programme was to clarify ill-defined or still unknown administrative boundaries. This problem of missing information was solved by defining spheres of influence associated with residential locations. Other countries that have undertaken similar projects include the United States (McMaster et al. 2005), Belgium (De Moor and Wiedemann 2001), Russia and South Korea.

11.4.2 … to the Oriented H-GIS Network

More recently, H-GISs have been developed to reconstruct engineering networks over time. Among the first of its kind, the 'Railroads and the making of modern America' project led by W.G. Thomas aims to show how, between 1850 and 1900, the railway network, which was new at the time, played a role in social, economic and political transformations and how this network contributed to federating the states into a nation. To this end, the geometric characteristics of the network were reconstructed and entered into an H-GIS, in order to draw up an inventory of the situations that marked the history of this network and compare them.

At the same time, I. Gregory took advantage of the work undertaken on the history of the population within the framework of the GB-HGIS to integrate the transport dimension into his research (Gregory and Schwartz 2009). The digitisation of the rail network was conducted using the atlas edited by Colonel Cobb and published in 2006. From this document, 31,000 km of track were digitised by a Spanish team under J.M. Henneberg. Analysis of the information thus digitised made it possible to verify the influence of the rail network on demographic dynamics (Gregory and Henneberg 2010). Building on this initial experience in the United Kingdom, J.M. Henneberg set about integrating different H-GISs on a European scale and over the long term, from the construction of the first railway network in 1825 to the present day. This programme has resulted in the publication of a unique database covering 22 European countries. All of these databases have been digitised manually.

More recently, several teams have been working on automatic network detection on old maps. A first attempt was made by a US team (Duan et al. 2017; Duan et al. 2020) using a learning algorithm based on neural networks. A recent application of this method allowed the digitisation of 500,000 km of roads in what is now Turkish territory from 1880 (Can et al. 2021).

11.5 From H-GIS to Multigraph: Modelling Speed Along the French Railway Network Over Time

In 1827, France's first railway was inaugurated between Saint-Etienne and Andrezieux for goods. In 1832, the first passenger line was opened between Paris and Saint-Germain-en-Laye. During the growth phase of the French railway network, more than 50,000 km of track were laid and more than 10,000 stations built. The first section will describe the sources and the way the network was digitised. Unlike roads, where people can enter the network at any point, the railway network is discontinuous: the second section describes how to deal with access to the network. Finally, it consists of the construction of a new research instrument: a generic multimodal multigraph.

11.5.1 Digitalisation of the French Railway Network

In accordance with traditional issues of H-GIS, the digitalisation of the French railway network uses a variety of sources. As there are no historical maps of railroads at regular time intervals, we used a contemporary shapefile of railways. But between 1930 and today, more than 20,000 km of railways have been closed: we used a map from the French National Railway Company (SNCF) of 1944, digitised by the French National Library, to add a lot of past segments manually. To attribute temporal characteristics to spatial objects, we considered several secondary sources. Some railway enthusiasts published a 'Chronological history of the French Railway Network', and others published 'Trains oubliés, les petits trains de jadis'. These sources provided information about opening and closing dates. Other variables have been added, like the rail company owning the lines or the electrification date. The same work has been done for stations. Around 56,000 km of railway lines and about 11,000 stations are listed. At this stage, the H-GIS provides information about the structure of the network: how the extension of the network has reached all parts of the country over time and how many municipalities had their own station (Fig. 11.2).

The study of the dynamics of the railway network suggests the 'speed revolution' should be explored (Studeny 1995): railways caused an accessibility shock. As there are no large timetables for the whole of France, an estimation of speed along the network is the result of generalisation from secondary sources (Caron 1997; Studeny 1995). Nine categories of line have been created since 1840, describing level of service, technology used and capacity: for each of them and for each decade, speed parameters are associated with each stretch of track, and Fig. 11.2 describes the evolution of the network in terms of main, secondary and local networks.

This H-GIS consists of just two layers: a linear layer describing all the sections and a point layer describing all the stations. Classical spatial analyses could be made of the structure of the network to demonstrate the differences in density in France. They suggest inequality of infrastructure throughout the growth phase. At the beginning of the period, the region around Paris was the densest. Until 1900, there were clearly differences between the North and the South of

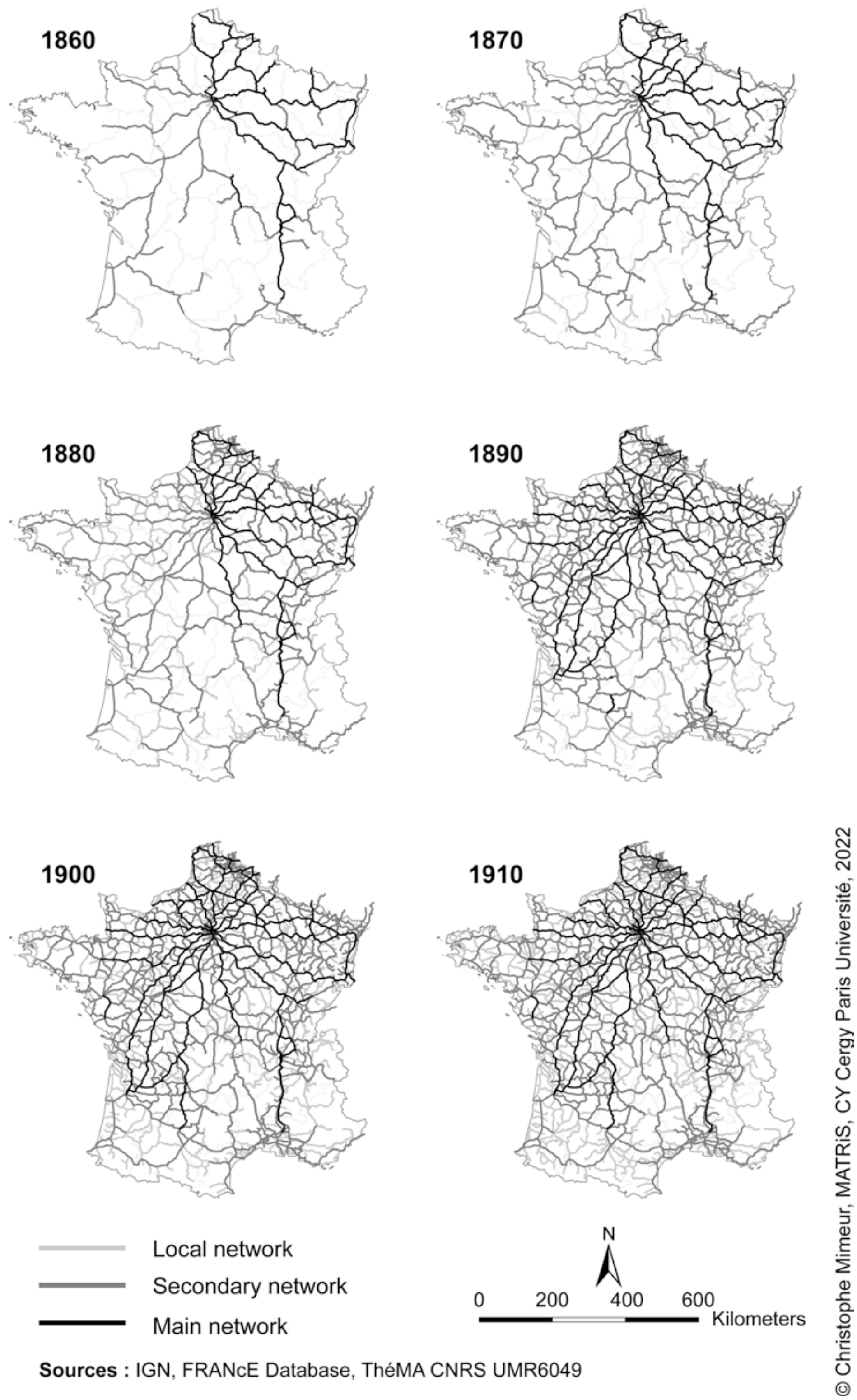


Fig. 11.2 The growth of the French railway network between 1860 and 1910

France, except for the Rhône Valley, which was served from an early date. Drawn up in 1878, the Freycinet plan developed 'lines of local interest' and extended the rail service to rural areas. However, some upland areas like the Massif central remained underserved. But in addition to these inequalities, there were differences in speed along the network: main lines were fast, but the speed slowed considerably along local lines.

To estimate travel time along a network, a graph is derived from the H-GIS. Nodes represent stations, and edges represent the path between two adjacent stations and are characterised by an impedance, as a travel time between the two stations. Dijkstra's algorithm solves the shortest path problem by calculating the fastest itinerary between pairs of stations.

11.5.2 Modelling Access to French Stations

Estimated accessibility measures between French stations omit almost two-thirds of French municipalities that were not served by railways. As the railway network is discontinuous (Stathopoulos 1997), this approach considered additional segments in an itinerary between two municipalities: people had to reach a station to take the train, sometimes far from their home. Studies of mobility in the long run suggest that most people walked to the station (Flonneau and Guigueno 2009). Beside the railway network, we add a new network, modelling the walk to the station. Rather than building segments to connect a municipality to the closest station, a complete pedestrian network integrates more solutions: using the segment to the nearest station may not be the best solution because walking to a more distant station may cut the journey time overall.

The pedestrian network is the result of the Delaunay triangulation between all the French municipalities, composed of 107,000 segments (Fig. 11.3). To estimate travel time, pedestrian speed parameters must be defined. On this question, we rely on the now classic historiography of the study of archaeology which suggests a decreasing function of speed according to the intensity of slope (Garmy et al. 2005). We use a Digital Elevation Model, BD Alti from French Geographical Institute, with a raster resolution of 250 × 250 m (Fig. 11.4). Each line of the pedestrian segment is associated with a slope parameter and according to this function:

$$\text{Pedestruab speed}_{ij} = \text{Maximal speed}^{*}e^{0.008\alpha^{2}}$$

where alpha is the average slope between i and j, we estimate impedance for each edge of the pedestrian network.

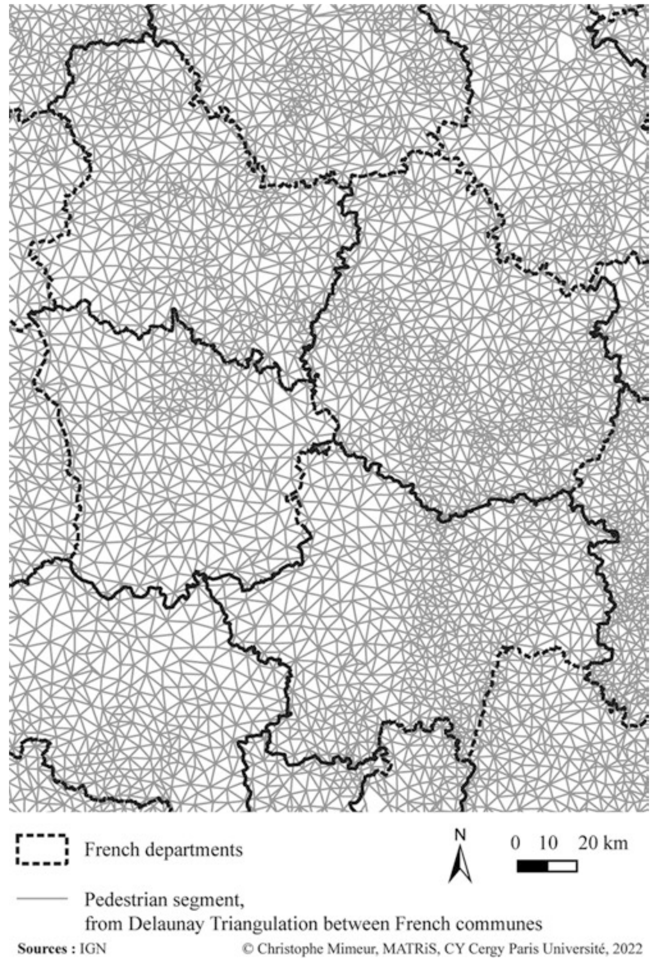


Fig. 11.3 Pedestrian triangulation among France's 36,000 municipalities

11.5.3 Building a Multi-graph

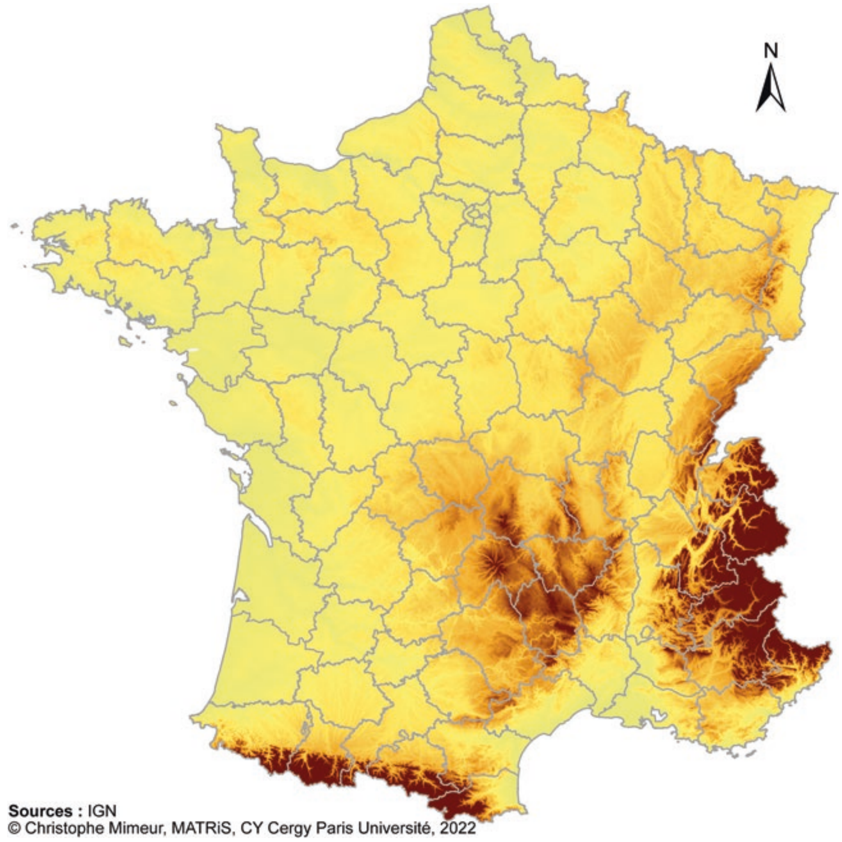
To assess travel time between all pairs of municipalities, using both pedestrian and railway segments, the multigraph is the union of the edges representing rail sections and the Delaunay triangulation. The difference between the two kinds of edges is the impedance: the first is pedestrian impedance, and the second is rail impedance. The speed along the railway network is at least six times higher than the walking speed. The nodes are all French municipalities. To facilitate processing, we associate the station with the centroid of the municipalities served.[1] A multigraph is obtained for each 10-year snapshot. Figure 11.5 is an example of the multigraph for 1890.

The method described is generic. Users could add more networks but must be careful about the consistency with behavioural models. The classical Dijkstra algorithm ignores the transition from one graph to another: particular care must be applied to modelling the interconnection between graphs.

Like the H-GIS, the multigraph is composed of just two layers: the linear layer and the point layer. Graph theory can be used to compute travel times between all pairs of French municipalities, which could be costly so users must be mindful of the indicator they are looking to construct.

[1] More sophisticated multigraphs exist where the centroid of municipalities served and the point representing the station are different. Interconnected segments must be added.

Fig. 11.4 DEM of France



11.6 Metrics and Networks Applied to the French Railway Network Over Time

Network properties computed from graph theory can be used to describe the triptych of the spatial network theory we explained earlier. This section questions the structure and the dynamics of the network by closeness/betweenness centrality over time and questions the logic of the network in terms of functional accessibility. The next maps and calculations have been made with the Morpheo plugin of QGIS (Lagesse, 2015).

11.6.1 Structural Accessibility

First of all, structural accessibility is measured by the closeness centrality index. This metric was used as early as the 1950s by structuralist sociologists and has been further developed since (Freeman 1978; Pablo-Martí et al. 2021). Closeness centrality measures the degree of interaction of an arc with all the arcs that make up a graph. The maps represent the importance of the centre/periphery gradient of the rail network for the three periods studied (Fig. 11.6). The highest values highlight the centre of the graph, while the lowest values are located on the edges.

The 1860 map (Fig. 11.6a) perfectly shows the Legrand star centred on Paris, as well as the LPLM line: Le Havre-Paris-Lyon-Marseille. In 1842, the Legrand Act declared these lines to be priorities. In this first period, most of the main cities were connected to the capital, except for Nice and Brest. With the Freycinet plan, the construction of secondary and local lines profoundly modified the 1890 map (Fig. 11.6b). The heart of the network shifted south of Paris, and the mean accessibility represented in yellow extended over a large part of the country. Unsurprisingly, the lines at the ends of the network have a low degree of interaction. This is particularly true for the Mediterranean coast, the Pyrenees and the Atlantic coast. The 1910 map (Fig. 11.6c) marks the end of the construction of the local network. The changes are less remarkable than in the previous period. The lowest values concern the areas already mentioned, completed by the borders of the North-East (Alsace) and the North as well as a part of the Normandy coast. This indicator confirms well established statements in transport geography. However, according to Porta, the closeness metric is limited by an edge effect which does not allow the hierarchical organisation of a network to be observed. This multi-scale structure plays a fundamental role in characterising accessibility at any point in space. This limitation leads us to explore other indexes of centrality.

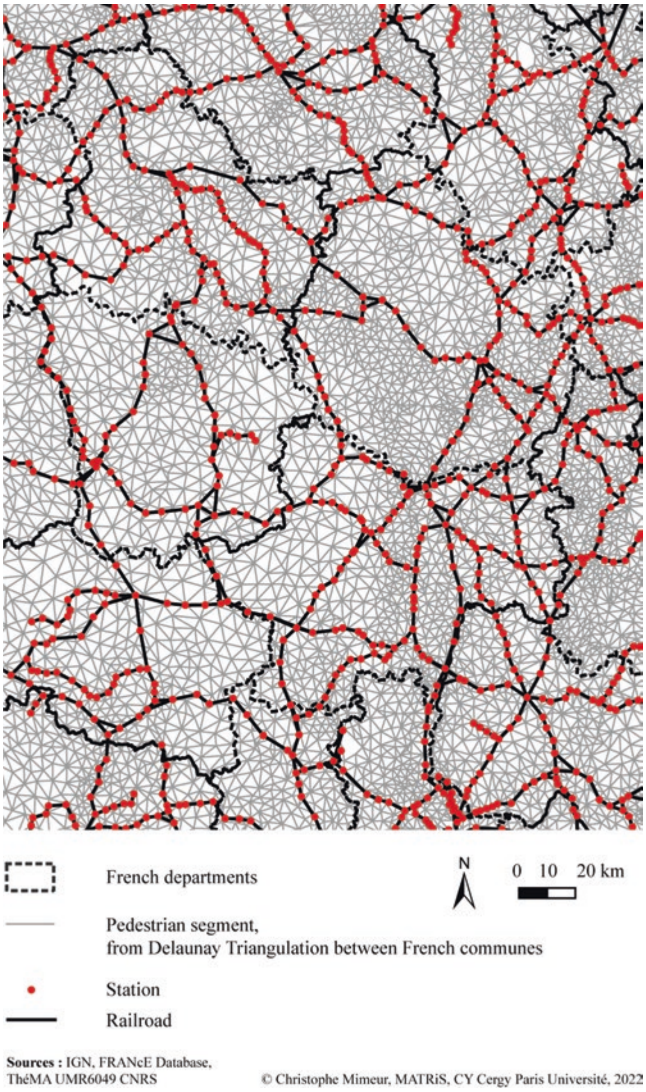


Fig. 11.5 The multigraph in 1890

To characterise the hierarchical structure of a network, a second approach consists in measuring the betweenness centrality (Fig. 11.7). This index refers to the number of shortest paths through a section. If a section has a high betweenness centrality, it means that it is located on many shortest paths connecting the other sections of the network. The 1860 map (Fig. 11.7a) shows a hierarchical organisation of the network connecting the largest cities in France. The lines from Paris stand out, as well as the line linking the Mediterranean to the Atlantic. The 1890 map (Fig. 11.7b) shows a slowing of this hierarchical growth. The structure of the network became meshed to serve a maximum number of county towns. This new arrangement was the direct consequence of the Freycinet plan introduced in 1880. The 1910 map (Fig. 11.7c) reveals smaller gaps. The hierarchical structure takes the form of a fishbone. The railway stars around the major urban centres are characterised by very strong betweenness centrality indexes. This result confirms the statements by Barthelemy (2018). Finally, some parallel routes show the competition that may have existed among the private companies of the time, such as the competition between the Bourbonnais route (Paris-Nevers) and a more central route (Paris-Orléans-Clermont-Ferrand).

This first structural analysis made it possible to measure the hierarchical organisation of the network based on strictly geometrical information. The advent of the train in the nineteenth century was also marked by shorter journey times. Did this contraction of space-time reinforce territorial disparities?

11.6.2 Functional Accessibility

The expansion of the railway network certainly made it possible to achieve new connections. In addition, this new means of transport, which contributed to the development of differentiated speed, radically changed this relationship to space-time (Ollivro 2000). Until then, the means of transport did not cause upheavals between geographical space and travel time. The arrival of the railway network caused a major disruption by introducing heterogeneous speeds.

To account for this differentiated acceleration, we will measure functional accessibility from Paris for the three periods defined earlier: 1860, 1890 and 1910 (Fig. 11.8). It should be remembered that the capital occupies a special position at the centre of the star network, designed by Legrand in 1842. The estimation of travel times is based on the speeds (pedestrian + train) assigned to the multigraph, explained in Sect. 11.5. The maps in Fig. 11.8 provide a picture of the accessibility potential, taking into account the difficulties encountered at each stage in the travel chain. The map of unipolar accessibility shows in blue the areas in the immediate outskirts of Paris, i.e. within 2 h travel time. The areas shown in green benefit from good access with trips taking a maximum of 8 h. Finally the accessibility of/from zones more than 20 h from Paris is categorised as poor.

The diachronic analysis shows a significant and progressive evolution of accessibility. The 1860 map shows marked inequalities in accessibility with a partial coverage of the country that extends up to approximately 400 km around Paris. The 1890 map shows a significant change in travel times throughout France. Bordeaux and Marseille benefited from better service due to the radial lines provided by the Legrand plan. Nice, Brest and Toulouse also benefited from significant accessibility gains. Cities north of Paris also enjoyed improved travel times. From 1910 onwards, the local network improved the accessibility of small municipalities, while the cities located at the ends of the network continued to see their accessibility improve. Nice was by then less than 24 h from Paris and Brest less than 14 h. Only

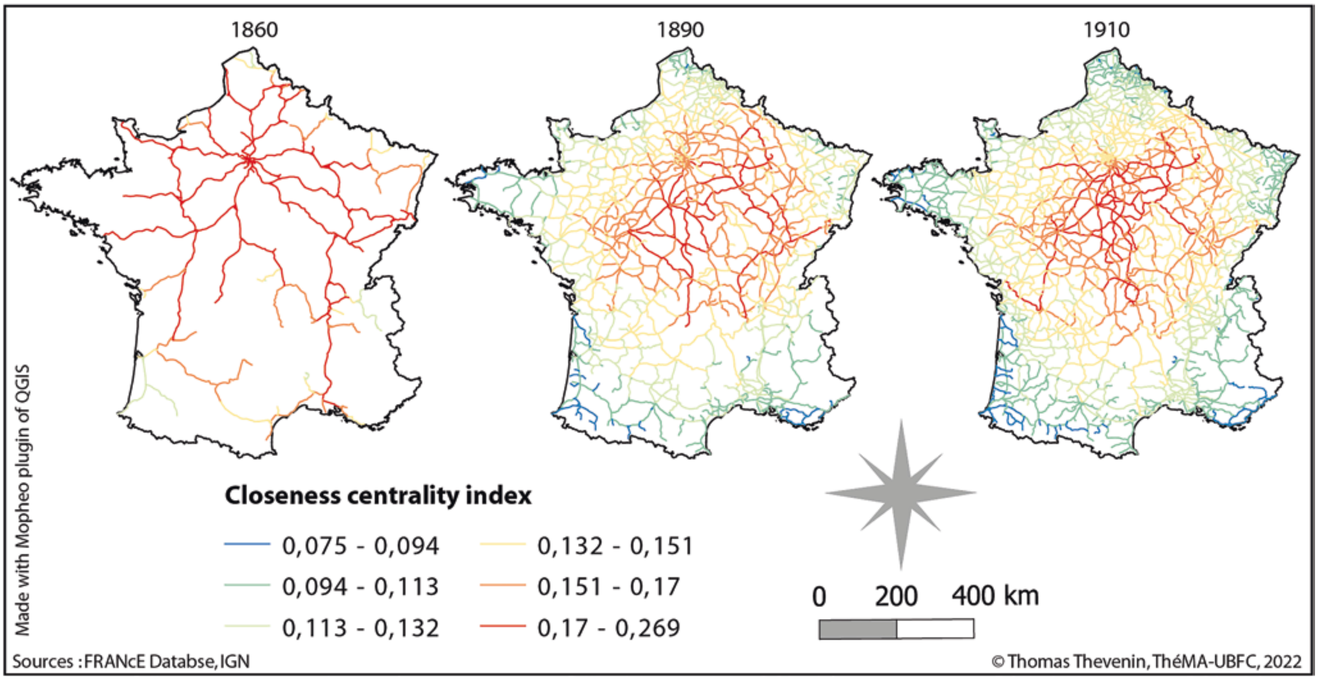


Fig. 11.6 Relative centrality: closeness centrality index

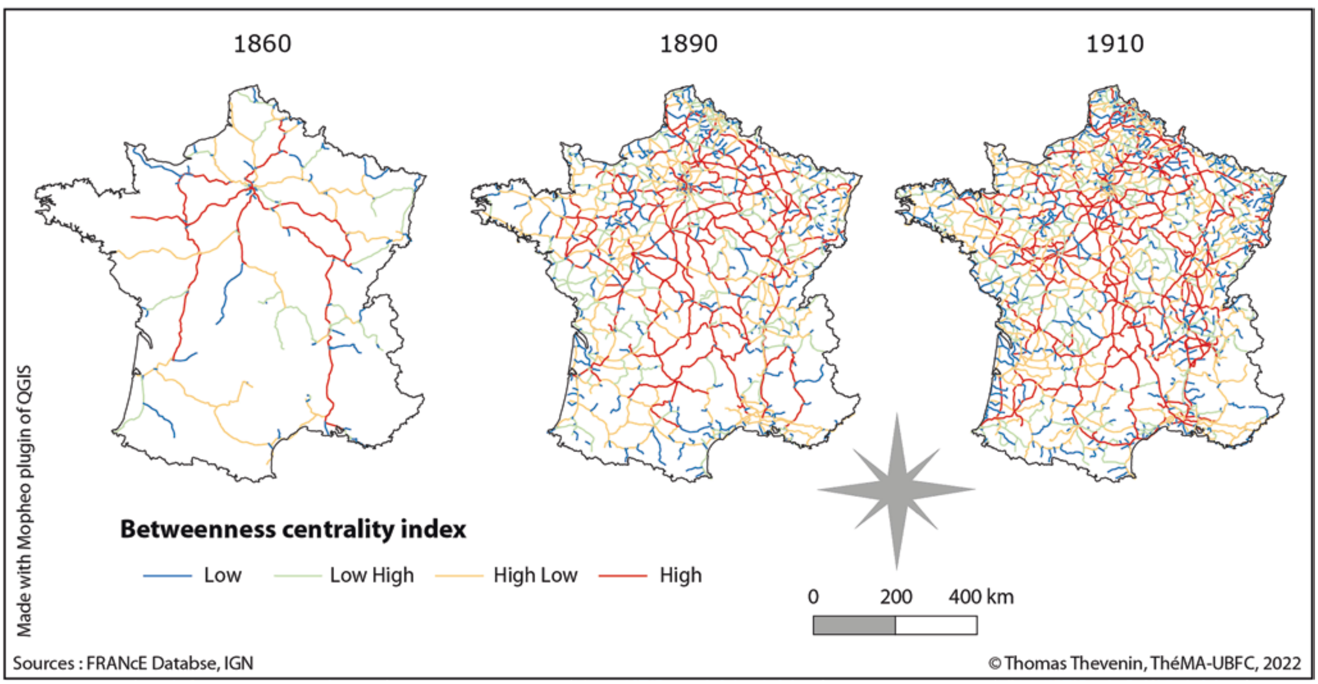


Fig. 11.7 Betweenness centrality

the most mountainous areas were more than 24 h from the capital: the Alps, parts of the Massif Central and the Pyrenees.

The results presented above have been aggregated so they can be shown on a national scale. However, the procedure can also be implemented on a finer regional or local scale, thus adapting the levels of diagnosis.

11.7 Conclusion

The aim of this chapter has been to review the use of geographic information systems for the analysis of geo-historical networks. To this end, the case study focused on the period of expansion of the French railway network from 1860 to

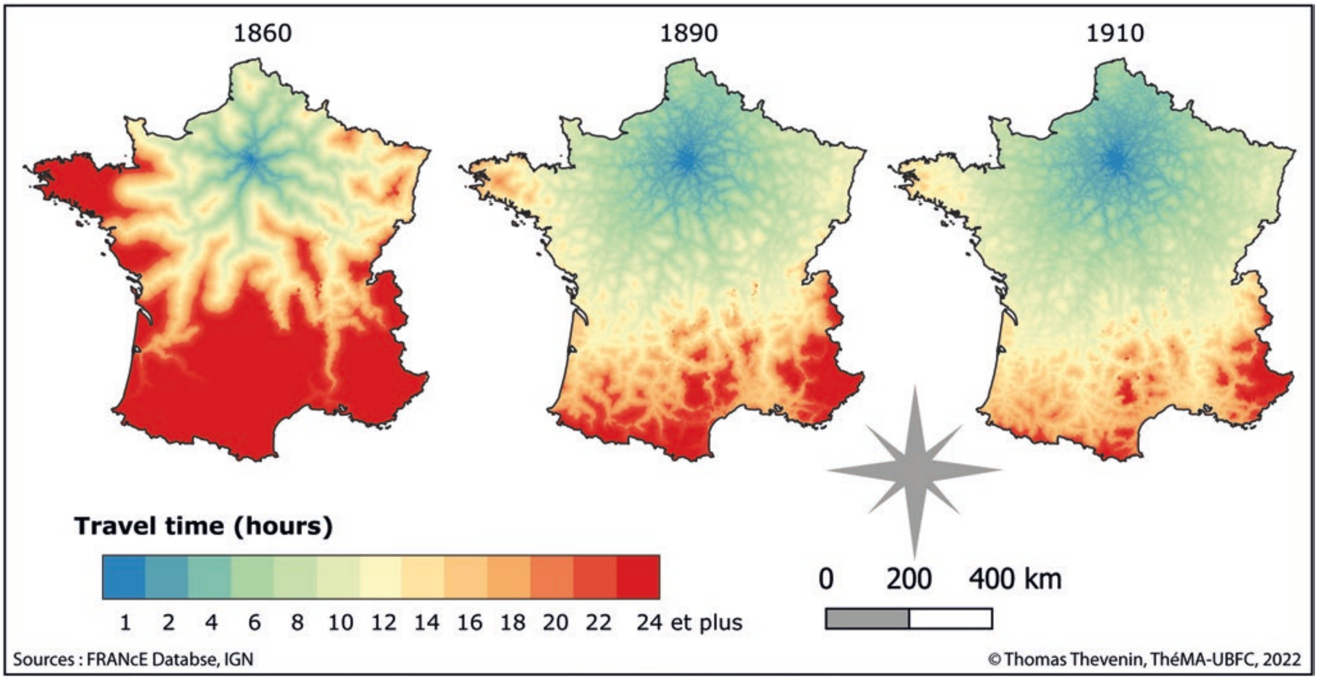


Fig. 11.8 Unipolar accessibility to Paris

1910. The methodological bias of this contribution is based on a processing chain fully integrated with open-source software (QGIS) and an open-source dataset (France database). To characterise the development of the railway network, we combined structural metrics to account for the geometry of the lines and functional metrics to account for the evolution of travel times over the long run. The resulting maps enable us to measure the pace of construction of this extraordinary infrastructure. In 1860, barely a third of France was connected to the network. Thirty years later, almost the entire country was connected to the network. From 1910 onwards, the local network made it possible to connect low-density areas, except for those located at altitude.

These indicators are efficient but suffer from several limitations. Closeness centrality measures limit the observation of a hierarchical organisation, due to an edge effect. To solve this problem, some authors suggest calculating this indicator on a local scale. Thus, Porta et al. (2006) propose considering the paths within a given radius. Concerning functional accessibility, the unipolar analysis centred on Paris must be completed by a more synthetic measure. A multipolar accessibility calculation can be used to moderate certain observations. Finally, only walking and train travel are included in this study in order to provide a better understanding of the dynamics of the networks. However, the effects of competition must be taken into account in order to characterise infrastructures over time. These various limitations are most often due to technical problems related to calculation time or data availability.

To overcome these various scientific obstacles, two main challenges are envisaged. The first concerns the development of a database capable of integrating a multimodal network composed of waterways, roads and railways. The ANR COMMUNES programme, in which we are involved, will make a complete multigraph available to researchers. The second challenge is computer-related. The aim is to mobilise sufficient computing capacity to generate and simplify large matrices and to store all the data produced. Solutions such as Openrouteservice (ORS) developed by the University of Heidelberg could be an interesting alternative. In the long term, these various advances will make it possible to continue the work undertaken with physicists on network morphogenesis. Other studies could be pursued in economic history in order to study the socio-eco-demographic dynamics in relation to the effects of the expansion and shrinkage of networks. All these examples demonstrate the interest of investing in the field of digital humanities to stimulate interdisciplinarity.

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Urban Morphology in Historical GIS

12

Jordi Martí-Henneberg, Mateu Morillas-Torné, Eduard J. Álvarez-Palau, and Bárbara Polo-Martin

Abstract

The way in which cities spread into their surrounding territories is a long-term process influenced by multiple factors. Some of these are related to physical factors, such as elevation (and more specifically, slopes) and hydrology, while others are related to human activities, such as population, transport infrastructure and economic growth. This is not, therefore, a random process. There are reasons that explain why cities have grown in the way that they have.

To better understand this process, it is important to demonstrate how cities have grown in both spatial and morphological terms: their level of compactness. In Europe, for example, the Mediterranean countries have a tradition based on urban compactness, associated with high population densities. However, recent trends have produced different patterns, leading to the consumption of more space. Patterns can change through history. It is therefore necessary to clearly identify the limits of built-up areas in order to know how they spread and to provide the best possible measurements of population density.

To analyse this process, we must first compile a comprehensive GIS dataset using a series of historic maps and aerial images. By georeferencing these old maps and aerial images, we will be able to digitise the shapes of cities in different years. It is, however, important to take into consideration the scale and projection of the maps, which may differ. In order to obtain a homogeneous GIS dataset with which to compare the evolution of the cities, we will show how to convert digitised polygons into a 100 × 100 m vector grid. This will enable us to morphologically harmonise all of the cities and periods studied. The result will be a Historical Urban Morphological Zone (H-UMZ) which will make it possible to identify the space occupied by urban zones over time. In this chapter, we will analyse and compare the cities of Barcelona, Manresa, Valencia and Almeria. We have chosen these examples as they allow comparisons amongst what are very different cases in terms of dimensions and characteristics.

Keywords
Urban morphology · UMZ · Historical GIS

12.1 Introduction

The city is a complex artefact that develops through a constant dialogue with its geographic environment. As the factors that interact in their constant transformation vary, cities have had to constantly evolve and adapt throughout history. Of all the themes presented in the different chapters of this book, it is perhaps the succession of changes that have taken place in each city that provides the best example of path dependency. The evolution of cities can only be clearly seen using GIS mapping which, in turn, depends on the availability of historic maps.

In order to help interpret these questions, the different sections of this chapter have been arranged in the following order: the importance of the subject of urban transformation; a selection of works related to urban morphology; a guide to creating GIS maps based on historical cartographic sources

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relating to Spain and how to approach such studies in other countries; and, finally, a reference to tutorials. With this in mind, the methodology has been designed so that it can be used to study any city, or group of cities, for which the necessary information is available.

12.2 Relevance and Interest of the Topic Treated

The expansion of the constructed space in cities is a subject of study that is common to, and has been widely treated in, various disciplines, including geography, regional planning and urbanism. The reason for this interest is the fact that the rhythm of urban growth, and the forms that it takes, has an impact on phenomena that are crucial to the lives of people, the natural environment, the planning of transport and economic growth. Given this context, it is easy to understand why public administrations have insistently intervened in fields such as urban and regional planning, through legislation and the application of different planning mechanisms. Given current interest in this question, the majority of studies of urban form have tended to focus on preparing for the future, based on an analysis of the recent dynamics of cities. As well as examining the concept of urban form, or morphology, in this chapter, we will also use the concept of "urban sprawl", or "peri-urbanisation", to refer to processes of unrestricted growth which, historically speaking, have shown less concern and respect for planning.

There are three questions that we shall examine in this chapter which have hitherto received relatively little attention but which have opened up a new, and very relevant, area for analysis. The first of these involves introducing the historical perspective; we have done this by using an approach that has allowed us to quantitatively compare the physical expansion of cities over time. This has permitted a diachronic analysis of both the individual evolution of each city and also that of groups of cities. Second, we have used data relating to the total population of each city to calculate the evolution of its density. This is a basic indicator for detecting changes in the compactness of the urban fabric. We shall also make specific mention of the effect that city walls have had on the development of the majority of cities in Europe. Their demolition, and how this facilitated seemingly unstoppable urban expansion, is another phenomenon that is also relevant to our study.

Within this context, the objective of the current chapter is to show how to measure the process of urban growth[1] by adapting historic cartography to a GIS. The time references will be determined by benchmark years running from the middle of the nineteenth century through to the present day. The reason for starting with this period is that it was a critical point in time, when there was an urgent need for cities to expand and certain historical features of city design were effectively made redundant by changes in military technology. In fact, these two factors combined to justify the removal of historic city walls. Another reason was related to the importance that railways were destined to have. This soon became clear, even though they still had a very limited development at that time, as shown in Fig. 12.1, which presents a map of the railway network in 1850. As we have already seen in Chap. 9, railways had a massive and direct impact on urban morphology, both because of their tracks, which created barriers, and their stations, which provided new spaces dedicated to transport and logistics within the city. Paths, roads and rails had originally dictated urban form to a large extent[2] and continued to do so in a massive way from the middle of the twentieth century, with the growth of motorised road transport.

The expansion of the constructed space was therefore a necessity which was a consequence of the consolidation of the industrial revolution and of the emergence of the first glimpses of the globalisation of supply chains. This manifested itself both in terms of technology and of sustained economic growth. The subsequent urban explosion was mainly the result of the concentration of economic activity related to industrialisation; improvements in living conditions and the resulting construction of new buildings; and the expectation generated by the railway and the steamship with regard to improvements in the distribution of food to cities.

As a result, cities grew, with very few of them missing out on this generalised process,[3] as can be seen in Fig. 12.2. In this figure, it is possible to observe that the growth of the urban population was a direct factor in the appearance of urban sprawl, although each case must be interpreted individually. The reason for this was that the factors responsible for growth varied enormously from city to city, as did local social dynamism, regional and national contexts, the position of each city in relation to the most dynamic areas of Europe and the physical characteristics of each location. Based on the comparative exercises that we propose in this text and in the tutorials, we will be able to note points in common, but without losing sight of the peculiarities of each particular case.

In this work, the use of GIS has enabled us to measure the dynamics of the changes in constructed space. We make an analysis of urban expansion, without going into general

[1] We will also use the concept of urban growth in the morphological sense, not just in terms of the growth of the urban population.

[2] See, among others, Alvarez-Palau et al. (2019), Guastella et al. (2019), Mustafa et al. (2018), Oliveira and Pinho (2006), Oueslati et al. (2015) and Salvati et al. (2018).

[3] These have been studied in the *Atlas of Shrinking Cities* (Beyer et al. 2006).

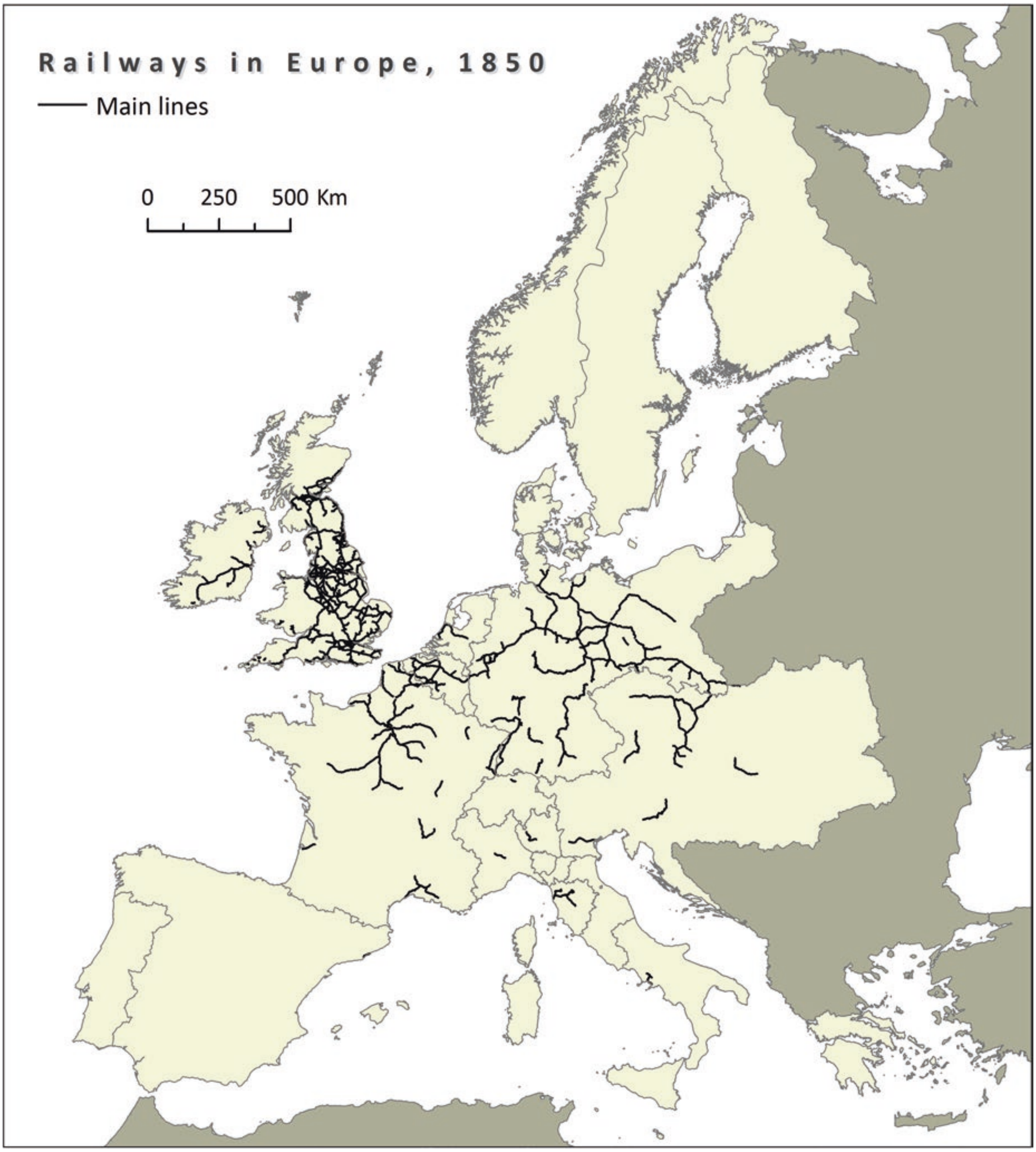


Fig. 12.1 Railways in Europe, 1850

explanatory factors which, as we have seen, are of a different nature. This is a very complicated subject, and it is unclear whether it is possible to precisely determine, or weigh up, the influence of each individual factor within this growth. Knowing these factors better, and also the roles that they have played, will call for a very detailed study of each city. This requires going to their municipal archives and examining notarial records which contain information relating to property deeds and the characteristics of each building project (this has been examined in Tatjer (1985)). However, compiling each monograph of this type implies so much effort that it is not very realistic to think that it would be possible to carry out this type of task in a comparable way for a large group of cities. Interesting references in this respect include the scientific and didactic materials contained in Oliveira (2021), which use the current property register as the base for reconstructing the evolution of urban expansion with the aid of automatic cartography.

In short, what we propose here is a realistic work programme and one that could be useful, from an academic per-

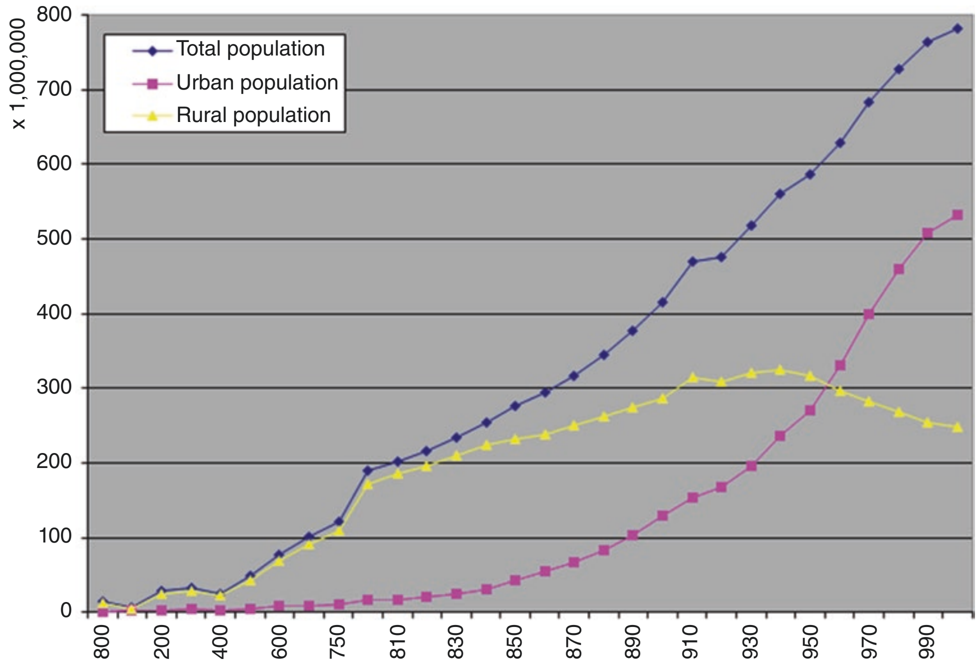


Fig. 12.2 Urban population in Europe as a % of the total, 1850–2020. Source: eGeopolis

spective, for research carried out up to secondary school level. As in the other chapters in this book, we shall finish by making reference to the content that is available in the online tutorial.

12.3 Studies of Urban Morphology

The field of urban morphology is very rich in contributions and points of view. What is more, its applied side, urban planning, has developed enormously in recent times. Even so, as with all artefacts that are anchored in the past, the city must be viewed diachronically, if it is to be correctly interpreted. With this in mind, we propose adopting a historical perspective in this chapter, based on the work of Moudon (1997), amongst others. His study of urban form can only be understood from a historical perspective, as the elements that define it have undergone continuous transformations. For Moudon, form and time are fundamental components of any research relating to the city.

The study of urban morphology has been included in various different areas of research: the geometry of urban sprawl, the study of different construction methods in cities, the analysis of population and building density and the study of land use and mobility. As already mentioned, in this chapter, we shall focus our analysis on the growth of the area of the urban surface and on the study of compactness, based on the density of the urban population. We will first present the main themes explored by the discipline of urban morphology. Then, in a second subsection, we shall look at studies that have more specifically focused on urban sprawl. Taken together, this should allow us to establish the necessary context.

12.3.1 Literature on Urban Morphology

In order to select the reference bibliography, it is necessary to start by defining what we understand by the term "urban morphology". Amongst the different proposals that have been made, we highlight that offered by Cowan (2005): "the study of the urban form". Starting from this rather open, yet clear, idea, the following general overview of different contributions and points of view will allow us to contextualise our own contribution. According to Oliveira (2022), the core theme of urban morphology is the study of the three main types of urban tissue found in cities. The first of these are public spaces which, in turn, can be subdivided into areas destined for leisure and circulation. The latter mainly consist of streets. These are some of the most stable elements in cities, and that is why they have been used as points of reference in many historical studies. The second type of urban tissue is formed by urban plots, which mainly involve private property. Finally, there are buildings, which normally have various uses. According to Oliveira (2019, 2021), these three types of urban tissue must be interpreted by analysing the agents of urban change and studying the process by which the transformation of urban form has taken place.

Based on this thematic and conceptual framework, we should remember that our approach consists of studying cities according to two different criteria: their evolution over time[4] and by creating a comparative GIS database to track this evolution. In the previously cited recent publication, which summarises the theoretical bases, methods and development of urban morphology, Oliveira (2022, p. 8) states that "…cities are indeed the result of a long process of construction, developed over centuries, and where different layers are continuously overlapping without erasing the previous layer". The historical vocation is therefore clear in a large number of the studies of urban form. Oliveira also presents the main approaches to urban morphology. These can be parcelled together in the historical-geographical approach, which was promoted by the school founded by Muratori (Oliveira 2016) and developed by J.W.R. Whitehand (2009) and by Vilagrasa (1998), in Spain. This is the line of work that we shall use in this chapter, although there are also other powerful currents. These include space syntax (Hillier 2016) and various forms of spatial analysis: cellular automata approach (Batten 2007) and agent-based models and fractal analysis (Batty and Longley 1994).

As well as examining the historical dimension in studies of urban morphology, the angle that perhaps most interests us in the work of the previously cited authors is their insistence on the need to carry out comparative research. This is a key challenge if we are to move forwards from monographic descriptions to global studies. One fundamental way to help us achieve this is to involve the use of GIS and/or other automatic mapping programmes (Oliveira and Pinho 2006) in historical analyses, although this is not yet very common. There have been some valuable exceptions to this rule (Pinho and Oliveira 2009; Vis 2018), but as we initially indicated, the use of GIS has mainly been limited to modern-day analyses of urban morphology (Ye and Van Nes 2014).

According to Oliveira (2019), the difficulties involved in carrying out comparative studies are various. They include the fact that existing case studies have often been carried out in different languages and within the contexts of different disciplines. For a comparative study, it is necessary to use the same concepts and methods, but as these have tended to vary, only a limited number of cities can really be directly compared. The efforts made to achieve this common base have not really borne much fruit until relatively recently, with the use of the same approaches in different geographic contexts (Conzen 2008; Whitehand 2009). This line of work has studied urban morphology, comparing the different types of urban fabric, their road connections and building models. Such a level of detail poses an interesting challenge but implies that it is difficult to make good comparisons. For this reason, in this chapter, we propose a simpler and more general way of working but one with greater analytical potential.

[4]Various authors have coincided in recognising the importance of the historical perspective (Whitehand 2009; Capel 2002).

12.3.2 The Historical Dimension in Studies of Urban Sprawl

As for the literature that has allowed us to interpret this theme, it tends to be either very extensive or very limited, depending on the perspective taken. If we take studies of historical urban growth as our point of reference, the number of works available is immense, and they refer to all the different types of cities in the world. There are also numerous studies if we adopt an economic, morphological or demographic approach to the urban phenomenon. These types of works are what have allowed us to establish a general framework. There have, however, been extremely few, comparative historical studies of urban sprawl to date. The reason for this is that few investigations have proposed developing a quantitative and comparative methodology based on historical urban cartography for a large set of cities over an extended period. This is what makes this chapter unique: it adopts a perspective that allows us to make a comparison of a wide range of cities (the case of one country is used as an example in Sect. 12.4), but it can also be applied to other areas. In a similar way, the sources and database that we have compiled for this study will help shape the methodology for later works. In them, it will not be possible to determine the factors that explain the different forms that urban expansion has taken, but it will help reflect upon them. One way to quantify this expansion is to calculate urban density in relation to the physical growth of cities. In the phases of urbanisation outlined by Antrop (2004), it is possible to note how the population initially concentrated in the centre of the city but then later moved to the suburbs. The result was a loss of population by the centre in favour of the periphery. In general, the cities have grown in size over time, and yet, at the same time, they have become less densely populated. In this work, we will study the extent to which the behaviour of cities has followed this pattern. In this same vein, a number of specific studies have also been conducted that have focused on the urban fringe.

Urban population density has been widely used as a measure and indicator of compactness (Pont and Haupt 2010; Navarro Vera and Ortuño Padilla 2011; Garcia 2016). Traditionally, urban compactness has been associated with a greater level of efficiency: this is true socially, as this limits the need for displacements, and economically, as it reduces the cost of providing transport and utilities (Newman and Kenworthy 1989). Along the same lines, Henry (2007) analysed the costs and benefits of the dispersed, or low density, urban model and concluded that it was associated with more negative features. It is evident that, if we assume a monocentric city model, compactness is closely associated with the cost, measured in both time and money, of moving from any one point to the CBD. As a result, when technology makes it possible to reduce the cost of transport, the influence of the

CBD over compactness is usually reduced (Rubiera Morollón et al. 2015), and therefore the density of the city tends to fall. In historical terms, compactness was the norm in preindustrial cities, which were confined by their walls. The transition from the classical city to the modern city has been studied in many works (Capel 2002, 2011, amongst many others), but the best graphic documents are provided by historical atlases of cities. On the other hand, within the field of the historical evolution of urban form, a collective study of urban history has recently been put together (Opll 2011) which contains some ambitious precedents; although these have only really been significantly developed in Portugal, Spain and France (Guardia et al. 1994).

12.4 A New Insight as a Result of the Application of Specific Methods

As we have already noted, the novelty of the analysis that we propose here lies in the use of qualitative sources for quantitative purposes. The examples developed here should subsequently be used to apply this approach to other cases. In the cities that we are going to study here, it has been possible to quantify the different rhythms of growth of their built environments and the variations in the density of their populations. Furthermore, comparisons between the cities studied have led us to relevant and innovative conclusions relating to the process of urbanisation. These results show the interest of the approach applied and the potential for its future use in other countries. A similar approach has also been applied to the historical study of Dutch cities (Rutte and Abrahamse 2016), as we shall explain in Sect. 12.4.5. In this introduction, we shall present the theme based on the case of Spain.

In the first subsection, we shall look at the data needed for this type of study, and then, in Sect. 12.4.2, we will present the context of Spain, as a case study, and explain the selection of the sources that were available. As with other countries, it was not possible to begin this analysis of Spain before the 1850s due to the difficulty of obtaining comparable sources and data. Similarly, as in the majority of European countries, population censuses only began in the middle of the nineteenth century.[5] With regard to urban cartography for Spain prior to 1850, this was only available for a very limited number of cities (Urteaga and Nadal 2017). However, the period chosen (1850–2006) is sufficiently wide, and it is of great interest, as it includes the period of the greatest urban growth in history. In the case of Spain, this was when the most important transformations in urban morphology took place. These had already begun in some cities in the nineteenth century but reached their fullest development in the twentieth century (Terán 1999). It would be interesting to look back to periods prior to 1850, but this would not change the results of this research very much, as the variations in urban morphology were minimal in the majority of cases, if we compare them with today.

For a number of reasons, we will take an earlier work (Alvarez-Palau et al. 2019), which studied the provincial capitals of Spain, as our point of reference. Regardless of their physical sizes and populations, these capitals were points of reference for their respective populations, as they were places where services and public organisations were concentrated. This administrative capital status encouraged their mapping, which has facilitated the availability of information for our work. What is more, provincial capitals present a varied range, with regard to their sizes and characteristics, and are also spread across the whole of Spain's peninsula territory, in a relatively homogeneous way (Fig. 12.3). Similar distribution patterns can be found across much of Western Europe and particularly in countries that have followed what is known as the Napoleonic model, which involved the use of provincial administrative units (known variously as "counties" or *départements*, according to the country).

If we look at the population register corresponding to the 1860 census, there were only two large cities in Spain at the time: Madrid and Barcelona. The rest of the capitals had populations ranging between 10,000 and 150,000 inhabitants, with 5 having populations of fewer than 10,000. The explanation for this lack of urbanisation was the lack of economic dynamism in the country as a whole. This also gave rise to a pronounced degree of emigration, particularly throughout the nineteenth century (Núñez and González Ruiz 2010). The domestic supply of new job opportunities only really emerged with the beginning of industrialisation which, from the mid-nineteenth century, was predominantly concentrated in parts of the Basque Country and Catalonia. These areas, together with Madrid, continued to lead Spanish development until the middle of the twentieth century, being virtually the only ones to do so. Spain had to wait for a change in economic policy before its rapid growth in the 1960s, which extended across the whole country. One clear consequence of this was urbanisation as a generalised phenomenon. In addition, in some cases (most notably Madrid and Barcelona but also Sevilla, Bilbao and Valencia), metropolitan areas emerged that grouped together neighbouring municipalities. In the next section, we shall provide methods for quantifying the physical growth of cities.

[5]Elden, S. (2007). Governmentality, calculation, territory. Environment and Planning D: Society and Space, 25(3), 562–580.

Randeraad, N. (2011). The International Statistical Congress (1853–1876): Knowledge Transfers and their Limits. European History Quarterly, 41(1), 50–65.

Fig. 12.3 Map of the Spanish provinces and their capitals

12.4.1 Data Required to Study the Evolution of the Density of Population

Determining the constructed area is the most complicated part of calculating the density of a city. This is naturally based on cartography. The method for analysing the growth of the urban surface area that we propose here is based on three types of information sources. In chronological order, these are the evolutionary cartography of cities, historical aerial photography and the Urban Morphological Zones (UMZ)[6] of the European Environment Agency (EEA). We have gathered together reference data covering a period of at least 25 years for each city. The first period analysed was 1850–1875, and we have studied five more periods up 2000, plus an additional shorter period, up to 2006. Data relating to UMZ have only been available since 1990 but offer the advantage that they will be updated in the future. Aerial photography is available for the whole of Spain, based on flights carried out in 1945 and 1957. These were made over the whole country and are therefore comparable. Evidently, the years in which such flights were made will differ from country to country. For the period prior to this photography, the only sources of information are maps. We preferred to use topographic maps, when they were available. However, the challenge was in making these different maps comparable. The sources used varied from country to country, and this was particularly true of the oldest historical sources. When making such studies, it is therefore necessary to carry out research into the context of the country to which the cities studied belong. Nowadays, there are standard ISO map series which make it possible to determine the quality and charac-

[6] Urban morphological zones form part of a database that was created by the European Environment Agency with the aim of studying land use and the urban environment. See https://www.eea.europa.eu/ds_resolveuid/DAT-89-en.

teristics of cartographic products. These are the ISO 9001:2000, 19,113, 19,114, 19,138 and 19,115 maps (Robledo Ceballos and Reyes Gatica 2009). On the other hand, the different civil and military organisms of each state also had their own initiatives for the production of cartography.

The search for historic cartography in order to obtain information about the earliest periods analysed was the most laborious part of the documentation process. This required consulting archives, bibliography and Internet resources. In the case of Spain, more than 400 plans and maps, with different levels of precision, were compiled for the study, which covered 47 provincial capitals. As later explained, this was possible, thanks to tasks of documentary research carried out in the different historical archives that have taken care of their conservation: municipal, provincial and national archives and also those belonging to the Spanish military.

It is necessary to point out that historical cartography must meet certain specific requirements for it to be used in work of this type. The main condition is that it must be possible to identify residential blocks within the city, in order to measure its urban growth. With regard to scale, we established a minimum of 1:50.000.

The history of cartography is the framework that will guide us with regard to the sources available for work of the type proposed here. In this respect, it is worth remembering that planimetric precision has been an administrative requirement for fiscal and urban planning since the second half of the eighteenth century. The greatest advances took place in the major cities on account of their relevance and the difficulties involved in their management. In fact, this has facilitated studies of the type that we propose here.

The second group of data required to calculate density is, naturally, that of total population. In old censuses, the only information available related to the population living in a given municipality, without distinguishing between that living in its main nucleus and in any possible dispersed settlement. This source has been specified in earlier studies (Franch-Auladell et al. 2013). In urban municipalities of the type studied here, the immense majority of the population lived in the central nucleus, so using this technique to calculate the density of the whole municipal area should not distort the results obtained.

12.4.2 Research into the Case of Spain

This section is dedicated to making a more detailed examination of the case of Spain in order to provide a guide that could then be used to relate relevant sources to the methodologies that can be applied and the results that could be expected.

We have already provided a few clues relating to the case of Spain. As an initial source, we started by using a cartographic collection which refers to the initial period of our analysis. This is the *Atlas de España y sus posesiones de Ultramar* (Coello 1860).[7] Although the work by Coello was incomplete, the map series included 223 cities and towns, mapped at various scales, between the years 1847 and 1870. For the most important cities, the project took advantage of the Royal Degree of 1846, which made it obligatory for the city councils of the most populous settlements to produce a geometric plan of their respective cities. This collection of maps and plans placed Spain amongst the most advanced countries in the world in terms of its cartography (Terán 1999). However, this collection was a unique phenomenon in Spain; for the rest of the periods analysed, it was necessary to look at plans made by city councils and the Spanish armed forces. Similar detailed plans have also been included in travel guides[8] or published by commercial associations[9] or by major department stores. These have also been used for this work, when they were sufficiently accurate.

However, the sources available in the main map libraries cannot normally provide all of the information that is required for work of this type, particularly in the case of small cities. With this in mind, it is advisable to make direct arrangements with those responsible for the municipal and provincial archives, whenever necessary. In our case, we made such arrangements in the 28 cities for which we needed to complete our information. The results achieved varied according to the availability of the cartography of these institutions. However, these arrangements, which were made by telephone and email, did enable us to obtain a significant number of maps that were not otherwise available from national archives. Our collection of cartographic sources has now been made available online (Olazabal et al. 2019).[10] As a result of this compilation task, although some gaps remained, for certain specific cities and periods, it was possible to obtain the majority of the information that was needed.

As previously indicated, for later periods, we also used collections of aerial photographs. The first of these related to flights made between February 1945 and September 1946 (Fernández García and Quirós Linares 1997). This was the first aerial photography project to cover the whole of the Spanish peninsular[11] and is known as the "Series A" flight. It

[7] The maps and cities contained in these series have been republished and commented upon by Quirós Linares (1991).

[8] Example: Baedeker, K. (1897). "Spanien und Portugal". Leipzig, Alemania. Wagner & Deves.

[9] Example: Plans of Barcelona by Grandes Almacenes el Siglo for much of the first half of the twentieth century.

[10] www.ciudadyferrocarril.com/cartografia_urbana.

[11] Fernández García and Quirós Linares (1997) have speculated upon the possible existence of a previous flight carried out by the German

was followed by the "Series B" flight, which took place between 1956 and 1957. Both series were recorded by the US armed forces. These flights were made due to a need for accurate information about Spain's national territory well during the Cold War. From the Spanish perspective, the interest and driving force behind this project was that of having free access to what was a strategic resource of great value.

12.4.3 The Approach Used for the Homogenisation of the Data

As previously indicated, three types of sources were used: old maps and plans, aerial photographs and the recent UMZ of the EEA. The second and third sources are available for all countries in a homogeneous format, although the accuracy of these maps depends on each specific case, as it depends on the resources that were actually used to obtain them. Figure 12.4 shows the case of San Sebastián to illustrate how we proceeded to homogenise the sources. First of all, when old plans are compared with other cartographic material, it is necessary to resolve a series of problems, such as differences in terms of scale and orientation (Koster 1998). Each source presents its information in a different way; it was therefore necessary to homogenise it in order to model the evolution of urban morphology over the study period. As a result, we created a comparable database which shows urban growth from the middle of the nineteenth century until the present day.[12] In other words, we were able to establish the Historical Urban Morphological Zones (H-UMZ).

The first sources used were those of historical cartography. This referred to different maps that had been produced over time and which are now practically obsolete as they do not show the current reality; even so, they are not without interest. When creating the H-UMZ, old cartography is valuable precisely because it shows the past. In the case of aerial photographs for Spain, the IGN has distributed the images taken from the American flights (1945–1946 and 1956–1957) and also those obtained from the *Plan Nacional de Ortofotografía Aérea* (PNOA), which have been updated at 3-year intervals since 2004. These images tend to be georeferenced, so their utility is direct. There are also other sources of recent data, such as the UMZs[13] and the CORINE Land Cover (CLC),[14] which have been produced by the European Environment Agency (EEA), and the Land Use/Cover Area frame Survey (LUCAS),[15] which forms part of the Eurostat framework (GISCO). Finally, it is necessary to highlight the *Sistema de Información sobre Ocupación del Suelo de España* (SIOSE), whose objective is to generate a land use database for the whole of Spain at a reference sale of 1:25.000,[16] which is another relevant source of information for this country.

Working with these materials, the first thing that we did was to adapt both the old plans and the aerial photographs for their treatment in GIS. The majority of the old plans were not georeferenced, and the aerial photographs from the American flights[17] included some serious errors, especially in Series A. Georeferencing historical plans would have been too costly due to the sheer number of plans and may even have proved impossible in the case of major geometric distortions between reality and the old plan.

For this reason, instead of georeferencing, we identified the elements represented in the historical sources that appear in modern cartography and, more precisely, in the land registry. We did this by visual identification, introducing an attribute into each unit, or block of housing, in the cities in order to show at what date each constructed unit first appeared. In this way, we obtained a database that showed us evolutionary urban growth in the form of different irregular blocks of housing being added to each municipality (see the example for San Sebastian; Fig. 12.4). The final step was to convert this irregular database into a homogeneous and comparable, 100 × 100 m mesh, for each year: the H-UMZ. Oliveira and Pinho (2006, 2009) used a similar approach for their study of the urban morphology of Lisbon and Oporto, although they did opt to georeference old plans, given that they were only analysing these two cities.

In summary, our work has consisted of passing from polygons, representing blocks of housing within cities, to the previously mentioned 100 × 100 m (or pixel) mesh, which delimits urban areas in a homogeneous way, for each of the periods studied. Continuing in this line, we then proceeded

military due to the fact that in some cases, "Series A" was known as the "German flight". However, there are no known records of this in the archives containing documentation dating back before 1945.

[12] This has followed the line of research that the authors of this article (Alvarez-Palau 2016) previously carried out on medium-sized cities in Catalonia.

[13] Do not confuse these with the H-UMZ. The UMZs are produced by the EEA, and the latest version dates from 2006 (https://www.eea.europa.eu/ds_resolveuid/DAT-114-en).

[14] CORINE Land Cover products are available in both raster (100 resolution) and vector (ESRI and SQLite geodatabase) formats. The minimum mapping unit (MMU) for the CLC is 25 hectares for areal phenomena and 100 metres for linear phenomena. The time series (1990, 2000, 2006, 2012 and 2018) are complemented by change layers, which highlight changes in land cover with an MMU of 5 ha (https://www.eea.europa.eu/ds_resolveuid/UCP8ANSW2E).

[15] LUCAS stands for the Land Use and Coverage Area frame Survey. Eurostat has carried out this survey every 3 years since 2006 to identify changes within the European Union in land use and land cover(https://ec.europa.eu/eurostat/web/lucas/overview).

[16] https://www.siose.es/.

[17] Available on the website of the *Centro Nacional de Información Geográfica* (CNIG), which depends on the IGN: http://fototeca.cnig.es/.

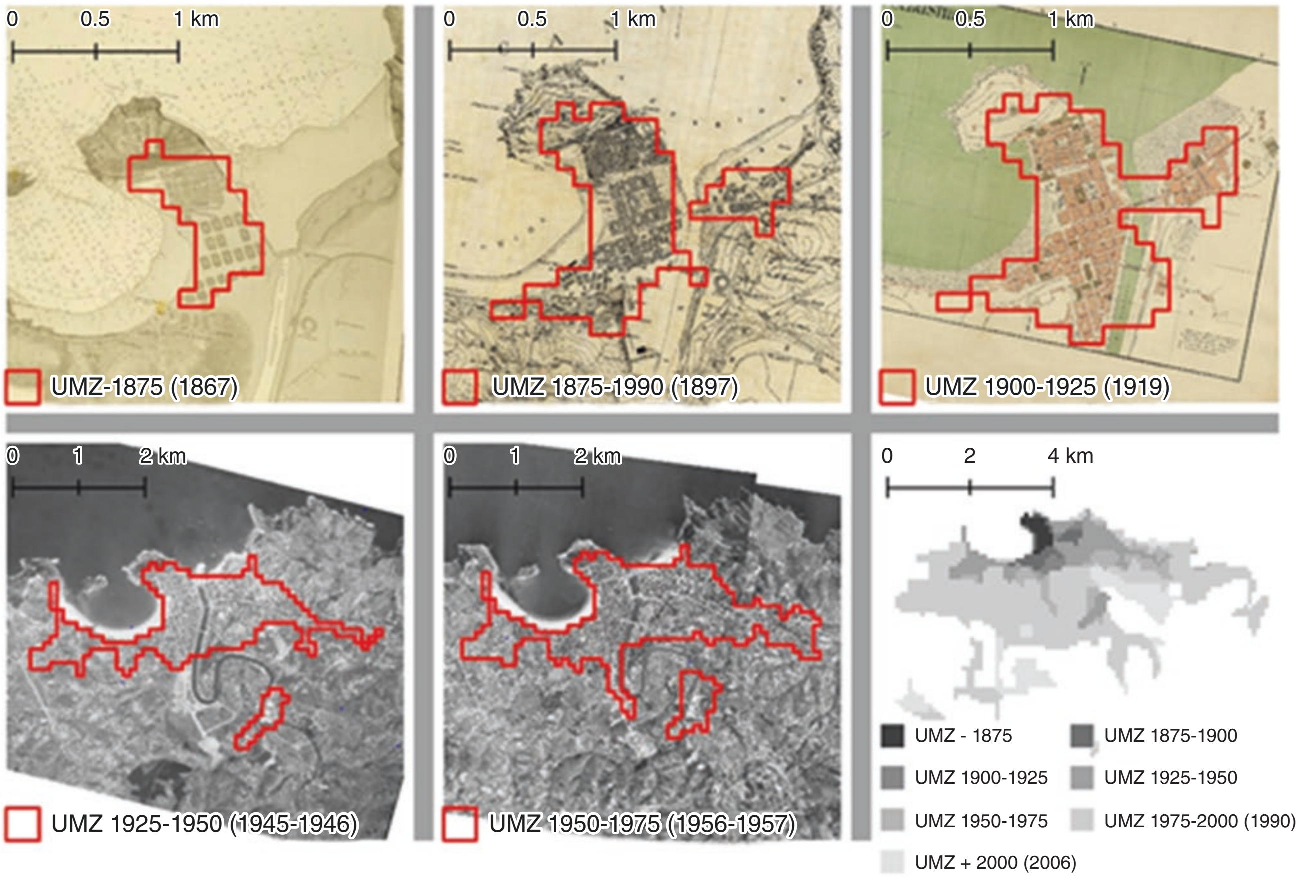


Fig. 12.4 San Sebastián. Source: Alvarez-Palau et al. (2019)

to study the criteria that the EEA used for calculating the UMZ, which were developed by Simon et al. (2010). The UMZ of the EEA group together urban, commercial, industrial and gardened areas and also river courses and communications routes, whenever these are within 200 m of built-up areas.

It is necessary to maintain stable methodological criteria in order to make the main characteristics of the sources used and the H-UMZ compatible. First, we generated various polygons to group together all of the blocks of housing dating from the same period and to thereby obtain urban areas. For the calculation of these areas, we established a maximum distance of 200 m between blocks of housing in order to consider them part of the same area; working in this way, we also included transit routes belonging to the urban area. The criterion of a distance of 200 m has also been adopted by other authors when defining urban agglomerations (Denis and Moriconi-Ébrard 2009).

As previously mentioned, the UMZ are, by definition, groups of urban areas that are all located within fewer than 200 m from each other. The next step therefore consisted of aggregating the previously obtained urban areas within the same polygon. In order to make a comparison with the UMZ, we then transformed the urban sprawl obtained at the previous step into another polygon formed by 100 × 100 m pixels.[18] Finally, we eliminated any polygons that were smaller than 25 ha in area in order to comply with the norm of the minimum mappable unit size. We therefore orientated the methodology to stress the fact that the urban sprawl within the municipal territory was diffuse, and clearly less relevant, in quantitative terms, than in the central city. Figure 12.5 presented a summary of the process.

In the next section, we shall detail certain aspects of a previously examined subject: the challenges involved in the task of combining different sources.

[18]The UMZ are presented in a polygonal vector file with the coordinate system ETRS89_LAEA_Europe. They were obtained by converting a raster file into a vector file with a resolution of 100 m.

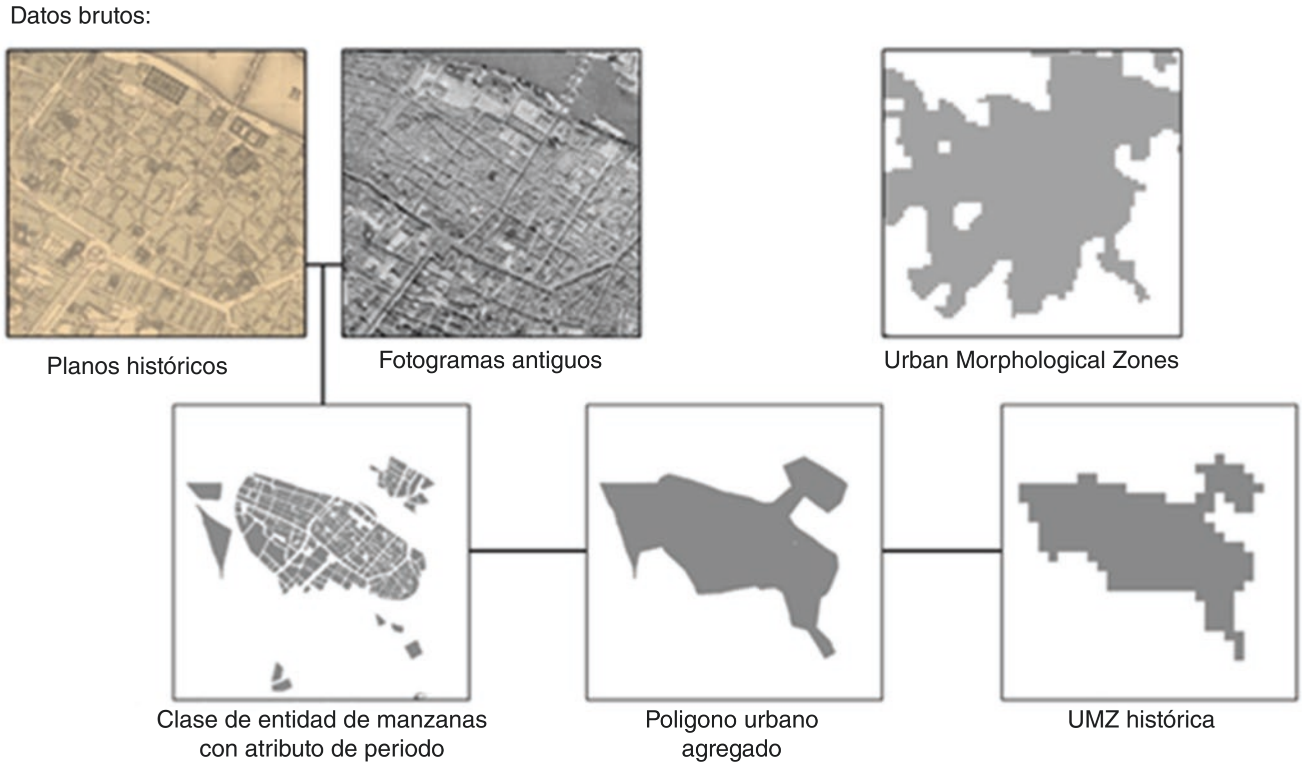


Fig. 12.5 Process of adaptation of the historical sources with the UMZ. Source: Alvarez-Palau et al. (2019)

12.4.4 Technical Difficulties Associated with the Use and Comparison of Different Types of Sources

The task that normally presents the greatest difficulties is combining historical cartography and old photographs with present-day maps. Finding spatial relationships between historical and recent sources is quite a subjective process because it is the researcher who looks for the similarities and differences in form, size and location. This implies difficulties that can be caused by differences in the ways in which cartography is processed to create new urban cartography. Old maps were not as precise as the databases in GIS format that are available to us today. This has implications when it comes to identifying the urban structures that figure in old city plans and relating them to today's base cartography; the possible geometric distortions of these plans make them difficult to interpret.

H-GIS studies of cities must therefore take into account the evolution of the techniques and typology of the cartography (Ariza López and Atkinson Gordo 2008) and the use that will be made of these maps to interpret the evolution of the urbanism of every city. Old cartography was used based upon its digitalisation using scanners. It is necessary, however, to take into account the degree of error in the scanning process; this means that the map that the researcher sees may not be completely accurate and reliable.

To compensate for this error, we were able to take advantage of certain advances in GIS technology. Before using the image of the historical map in digital format, it was necessary to take into account the georectification that would be required. For the moment, we have not studied the precision with which each map was made, although many of them have a scale that would seem to indicate a good level of accuracy with respect to reality. What is more, it is necessary to take into consideration the fact that old maps were not always created with the aim of providing exact geometric knowledge about the city. Instead, they were sometimes intentionally deformed in order to stress certain aspects of the city. The lack of certain measurements had a similar impact upon this deformation.

To carry out the georeferencing process, it was necessary to start with a modern-day image of the city provided by the *OpenStreetMap*, upon which we established several reference points relating to the old maps; in other words, we georeferenced them. We always tried to choose the same references, basing our work on historic buildings and streets that still exist, in order to thereby achieve the most faithful result possible. We can take the case of Burgos as an example. There, we chose points such as the Plaza Mayor (main square); the cathedral; the castle and its surrounding buildings, in the Las Huelgas area; some streets in the southern part of the city; and military buildings to the east of the city. We always sought to establish seven or eight points so that if it was necessary to obtain a smaller degree of error, we could finally remove two of them and keep the other six. We started from the hypothesis that the maps of Burgos used in this study had been compiled with precision (Polo-Martín 2020, 2021) and with the aim of serving their purpose. Based on this assumption, we carried out their geolocalisation and compared them with the current map of the city.

The use of old maps as sources of GIS data could present another difficulty because of changes to the internal structure of the city that occur over time (Andrés López 2011). Working in this way, and with blocks of housing, was equivalent to studying the road network of the city, which is the central theme of urban morphology. The road network, on the other hand, provides a point of reference, as the street layout is one of the most stable elements in a city. The modifications have only consisted of the widening of some streets or the opening of new ones, which has not impeded the transfer of information from the historical sources to the current base. However, in the suburbs of the major cities that emerged in the first half of the twentieth century, there have been some very important transformations to regenerate these areas. The fashion of low-quality urbanisation during the first half of the twentieth century did not come up to today's urban requirements. However, the subsequent improvements made to these areas have often modified the urban street map, making it difficult to identify the old limits to the urbanised area on the current spatial base. The solution has been to aggregate the whole urban area, by carrying out an exercise in which the streets and blocks of housing inevitably lose their importance, as the unit of comparison becomes the pixel.

As indicated in the section referring to Spain, the database that we obtained allowed us to chart the evolution of urban space in the municipalities studied. We did this grouping the data into periods of 25 years. Thanks to this approach, it was possible to use the pixel, which is smaller than a block of housing, as the unit of comparison.

The result obtained was a series of polygons that vary in size from period to period, as they show and delimit changes in urban areas. As shown in Figs. 12.6a, b, this has made it possible to measure their extensions and to cross this information with other types of data, such as population censuses, in order to calculate the density of urban population.

In the next, and final, sub-section, we shall present a line of work that is of great interest and utility. This is the study of cartographic materials for individual cities; in this case, we have taken the Netherlands as our point of reference.

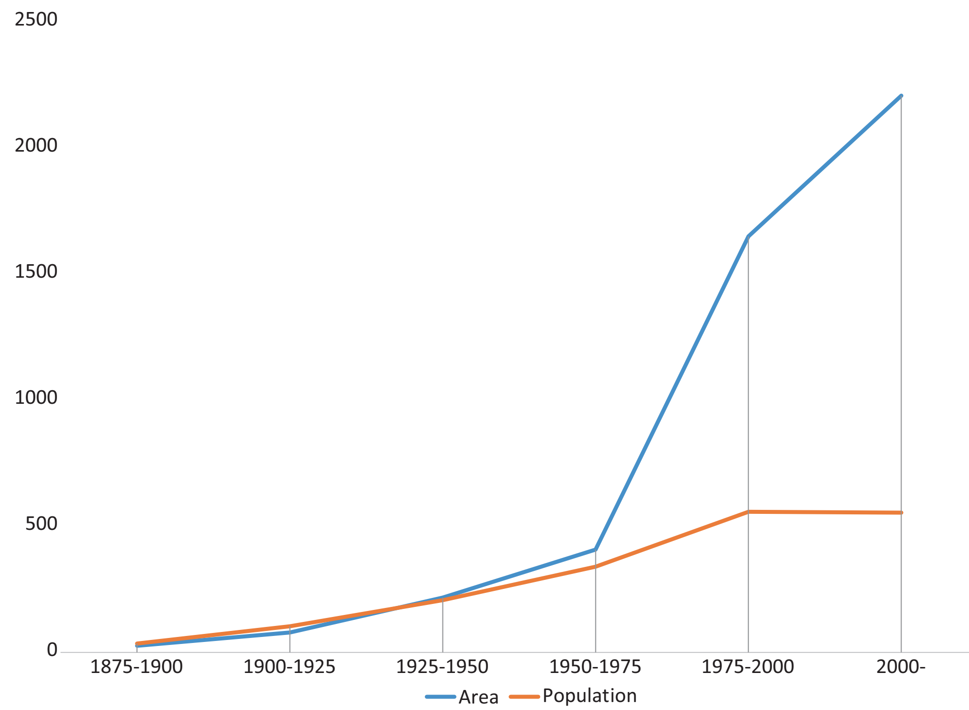
12.4.5 The Modern Atlas of Historical Cartography

In each country in Europe, there are numerous works on urban history which have reproduced a greater or lesser number of old maps. The majority of these are monographic studies of a single city or of a small number of cities. There are, however, much fewer syntheses that bring together and compare work based on a single country. In this context, it is important to make specific mention of the effort that has gone into compiling modern historical atlases of cities which not only present reproductions of relevant maps but also use them as a source for comparative analysis involving GIS. The most complete of these, and the one that we have used here, as our point of reference, is the *Atlas of the Dutch Urban Landscape* (2016). This is a piece of work which collects together information about a group of cities in a country with a long urban history and which is based on both a very extensive number of old maps and other more modern sources. In it, the authors have used automatic cartography in order to compare the different forms and typologies of urban expansion. In this way, they have achieved a clear level of visualisation and have also been able to make comparisons between cities. To achieve this, they used qualitative knowledge about each city and combined this with a quantitative database of information about them. In this way, they were able to produce and present a series of didactic monographs showing the evolution of each city while also offering some general comparisons.

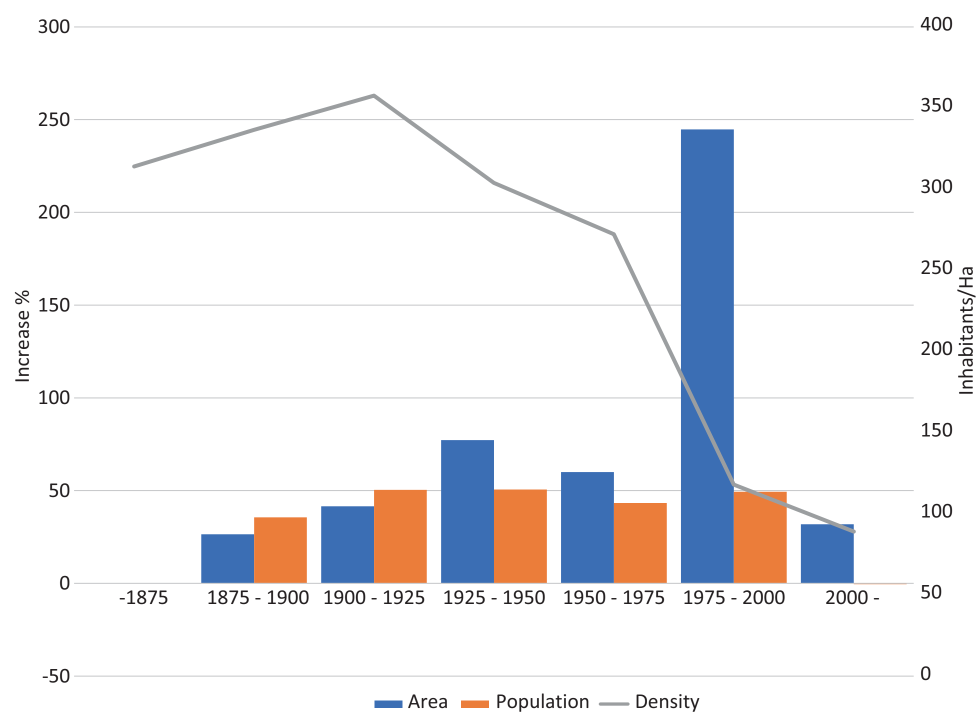
This atlas offers an answer to the question, "Why do today's Dutch towns look the way they do?" To carry out such work, this group of researchers first obtained an insight into the histories of the main cities in the country, from the eleventh century through to the present day. This atlas comes very close to our approach as it is based on Conzen's fundamentals of town plan analysis and also to those of other academics who created "The European Town Atlas Project" (Conzen 2008). In this atlas, it is important to highlight both the comparative long-term vision that was adopted and the fact that it combines data of various types: geographical, archaeological, morphological, urban, demographic and economic.

In this chapter, we shall select two of the cities studied in the atlas and use them as examples. The first of these is Breda (Fig. 12.7), which obtained its municipal charter in the thirteenth century and grew up near a castle, two waterways and three roads. From the old town (coloured in black, brown or red, depending on the period), the city mainly grew towards the south, prior to 1950 (yellow and green areas). The spatial expression of this growth was largely determined by the city's old roads and also by the villages that surrounded Breda, and particularly those lying to its south.

Fig. 12.6 (**a**) Total increases of area and population in the cities analyzed, in % (**b**) Variation between periods of the built-up urban area and the total population; and evolution of urban population density.



(a)



(b)

The second example has very different characteristics. This is Rotterdam (Fig. 12.8), which is a large port city. It stands at the confluence of the rivers Rotte and Meuse and originated as a trading settlement, back in the nineteenth century. Until the mid-nineteenth century, settlement was largely confined to the area that lies north of the river Meuse. During the second half of the nineteenth century (yellow area), the city underwent enormous expansion and extended

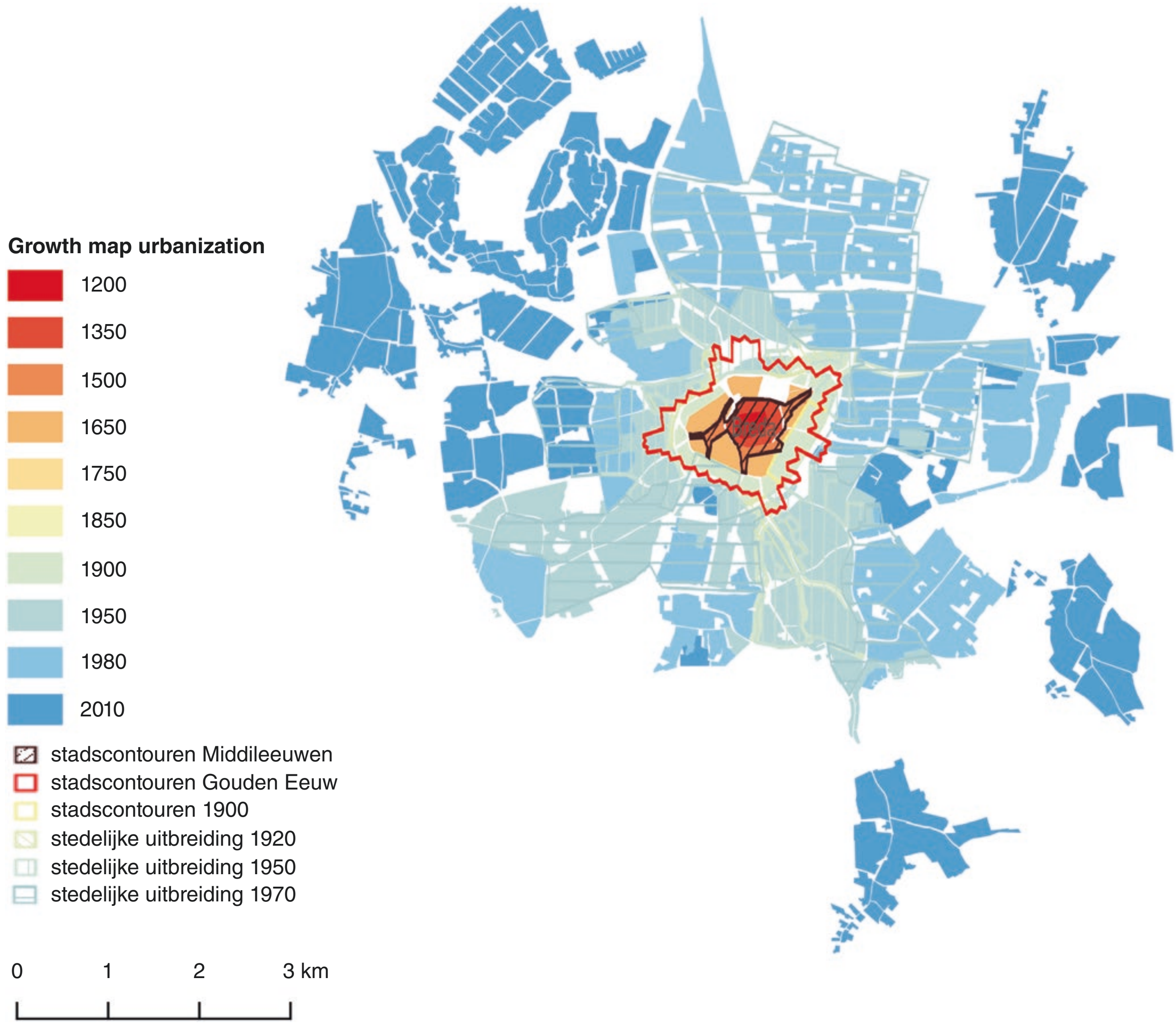


Fig. 12.7 Breda. Source: Abrahamse and Rutte (2015)

towards the south, along the left-hand side of the river. The city's consolidation as an industrial and commercial centre explains its exponential growth during the twentieth century.

The cartographic materials produced in the atlas are what permit a detailed analysis of the changes in the morphology of each city. The atlas published on paper has been complemented by other material which is available from a dedicated website, whose content is also relevant to summarise here. The *Atlas of the Dutch Urban Landscape* provides an online version of the map of urbanisation in the Netherlands. As indicated, the atlas shows how the country's cities have developed since their origins (as compact settlements enclosed by walls), through to their current forms which include suburban areas.

The information is provided via the Web Map Service (WMS) and Web Feature Service (WFS) protocol. These are two protocols that can be accessed using GIS software in order to visualise each of the layers that offer data in shapefile format:

https://www.nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search#/metadata/ff63434f-7b4a-4346-a4e2-2037adfbcf0c

The atlas data can be used to work with a web map application. In this atlas, it is possible to visualise each of the layers, to change their order, to zoom in on specific areas and to export the final map as an image. It is also possible to access the application via the following link (in Dutch):

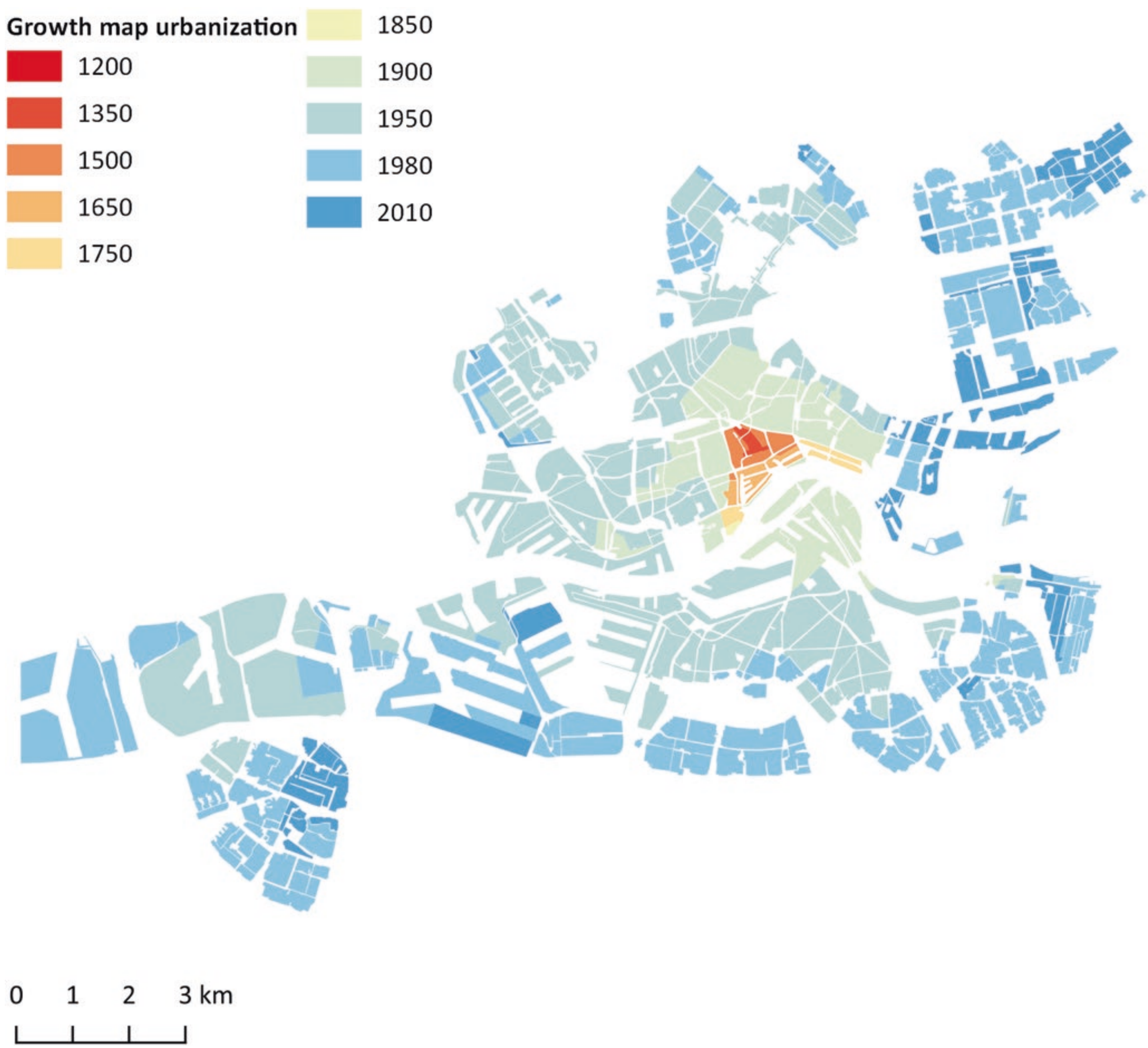


Fig. 12.8 Rotterdam. Source: Abrahamse and Rutte (2015)

https://rce.webgispublisher.nl/Viewer.aspx?map=VerstedelijkingNL

In the exercises in the tutorial, it is possible to study the previously described process in greater detail. To do this, we shall use data relating to the cities of Lleida (Spain) and the Hague: the administrative capital of the Netherlands. Both the previous explanations and this tutorial have been designed so that this type of study can be reproduced for any city for which similar data are available.

12.5 Tutorial

In this chapter, we will learn how to create Historical Urban Morphological Zones (H-UMZ). By definition, these zones have to be "a set of urban areas, which we have spatially aggregated with other neighbouring areas lying less than 200 m from them, excluding any elements that were smaller than 25 ha in area" (Alvarez-Palau et al. 2019).

The initial data are blocks of housing and a historic map. With the latter, we will be able to know whether each block of housing had been constructed prior to the year of the map. We will then convert the irregular shapes of the blocks of housing into a 100 × 100 m mesh. With this, we will be able to ensure that the H-UMZ are comparable.

We will apply this methodology to the cities of Lleida and the Hague as examples. However, we do this with the intention of presenting an approach that could be applied to any municipality. To do this – as in other cases – it will be necessary to collect information about the line that we indicated for cases that the reader wishes to analyse.

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13 The Network of UNESCO Sites: Changes and Patterns Visualised with Cartograms

Mario Blersch, Johannes Keller, Tobias Matusch, Lisa Dannwolf, and Alexander Siegmund

Abstract

The United Nations Educational, Scientific and Cultural Organization (UNESCO) is one of the most important international institutions for the conservation and protection of the world's cultural and natural landmarks. The UNESCO World Heritage Sites, the UNESCO Biosphere Reserves and the UNESCO Global Geoparks are locations with outstanding value for humanity and are spread all over the world. The distribution of these outstanding landmarks has been an international issue during the last decades. A GIS allows an analysis and visualisation of data over space and time and enables, among other things, insights into the effectiveness of international policy. Visualisations of spatial patterns, like maps or cartograms, offer various opportunities to form or manipulate the reader's view on the world.

In this chapter, cartograms are presented as a method for the visualisation of spatial data. A workflow to create and interpret cartograms with the open-source GIS Quantum GIS (QGIS) is presented. With the cartograms, the distribution over different periods of UNESCO World Heritage Sites, UNESCO Biosphere Reserves and the UNESCO Global Geoparks can be analysed and visualised much easier, as with maps or statistical values alone. The analysis visualises the global inequalities in the distribution of UNESCO World Heritage Sites, Biosphere Reserves and Global Geoparks and their changes over the last 50 years. The chapter aims to explain this advantage with an example as well as to teach students to work with vector data, to create cartograms with QGIS and to think critically about maps and cartograms.

Keywords

UNESCO sites · Cartograms · Biosphere reserves · GIS analysis

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13.1 Introduction

Since its foundation in 1945, the United Nations Educational, Scientific and Cultural Organization (UNESCO) has become one of the most famous international institutions worldwide. With its different programmes, UNESCO has transformed itself into an important brand for the protection of cultural and natural landmarks. Continuously, the list of UNESCO designated sites is growing. However, the last five decades have been characterised by global economic and political changes, which have also repeatedly made it necessary for UNESCO to adapt. The List of World Heritage in Danger shows impressively that even centuries-old properties confront ascertained and potential sources of danger (Badman et al. 2009). As the political and economic importance of UNESCO has increased, so has the media attention about UNESCO and its decisions. It is a balancing act to make sensible decisions as a global institution that affect the lives of individuals in different regions around the world.

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The constant increase of UNESCO designated sites can be shown very well using tables and graphs. However, the regional weighting and influence of certain policies can barely be displayed with tables and numbers, if at all. Maps can be helpful in making the spatial distribution over time visible. By using cartograms, warping a regular map based on a certain value, the different weighting of the individual regions can be shown even more clearly. This allows an interpretation of past developments and implementations of the individual policies of UNESCO.

13.1.1 United Nations Educational, Scientific and Cultural Organization (UNESCO)

In 1945, against the background of the massive destruction and upheaval of the Second World War, the United Nations Educational, Scientific and Cultural Organization (UNESCO), with initially 37 member states, was founded in London. The vision of UNESCO is to ensure peace and to foster intercultural understanding. This goal needs to be safeguarded not only by governmental arrangements on politics and economics but also by fostering dialogue and mutual understanding (Duedahl 2018). At the beginning of 2021, UNESCO counted 193 member states and 11 associated states. UNESCO is the only United Nations organisation with national commissions. These national cooperating bodies work with and support governmental and non-governmental bodies. They are important bodies for the establishment and management of UNESCO designated sites worldwide.

13.1.2 UNESCO World Heritage Programme

As an important pillar to preserve cultural and natural heritage as an outstanding value to humanity, UNESCO adopted the Convention Concerning the Protection of the World Cultural and Natural Heritage in 1972. Better known as UNESCO World Heritage Programme, UNESCO is compiling sites of outstanding universal value around the world. The list includes cultural, natural and mixed sites. It has become the "most effective international legal instrument for the protection of the cultural and natural heritage" (Strasser 2002) and an important trademark (Hassan and Rahman 2015).

However, since its adoption, the distribution of World Heritage sites has become a major subject of concern. Historic European towns and religious monuments (especially Christian monuments) were over-represented. It conveyed the impression that there were far fewer sites of universal value in other regions. A certain imbalance was identified early on, for example, by (Jokilehto 2005). As a response, UNESCO adopted various strategies to counteract this imbalance (Steiner and Frey 2011). This paper addressed this imbalance in Sect. 13.3 and shows the impact to the "Global Strategy for a Balanced, Representative and Credible World Heritage List" launched in 1994.

Due to the global reach of the UNESCO trademark, a high level of trust in transparent decisions is of utmost importance. According to the operational guidelines for the implementation of the World Heritage Convention (July 2019), the Global Strategy "is designed to identify and fill the major gaps", in particular by encouraging states to adopt the Convention and prepare their own tentative lists and nominate properties for inscription (WHC 2019). The impact of the Global Strategy and the general development of new designations are described and illustrated in Sect. 13.3.

13.1.3 UNESCO Man and the Biosphere Programme

As response to an increasing threat to nature (including biodiversity and landscapes) such as deforestation, urbanisation and human encroachment, UNESCO initiated in 1971 the Man and the Biosphere (MAB) Programme. After five decades, the MAB Programme, which initially started as an intergovernmental scientific programme for an improvement of the relationship between people and the environment, has transformed to a global network of protected areas. The focus of the MAB Programme is the 714 biosphere reserves in 129 countries, defined as model regions for sustainable development (UNESCO 2019a). UNESCO Biosphere Reserves differ significantly from other protected area networks such as national parks or nature conservation areas. Their main goal is to include the research on human-nature interactions and socio-economic processes in natural/near-natural ecosystems, identifying and analysing effects of climate change, ensuring basic human welfare as well as exchange and transfer of knowledge.

Over the past five decades, various strategies have entailed major change for the distribution of biosphere reserves and their configurations. This includes the Action Plan for Biosphere Reserves in 1984 (UNESCO 1984), the Seville Strategy in 1995 (UNESCO 1995) and the Madrid Action Plan in 2008 (UNESCO 2008) (see Fig. 13.1). In 1984, the MAB Programme extended the focus of conservation purposes towards scientific knowledge and sustainable development of biosphere reserves due to the scientific knowledge and sustainable development. Since the Seville Strategy in 1995 these extended objectives were allocated to different zones. Since 1995, every biosphere reserve has specified zones with functions such as a conservation function in core zones, a development function in buffer zones and a function to foster sustainable economic and human development in transition

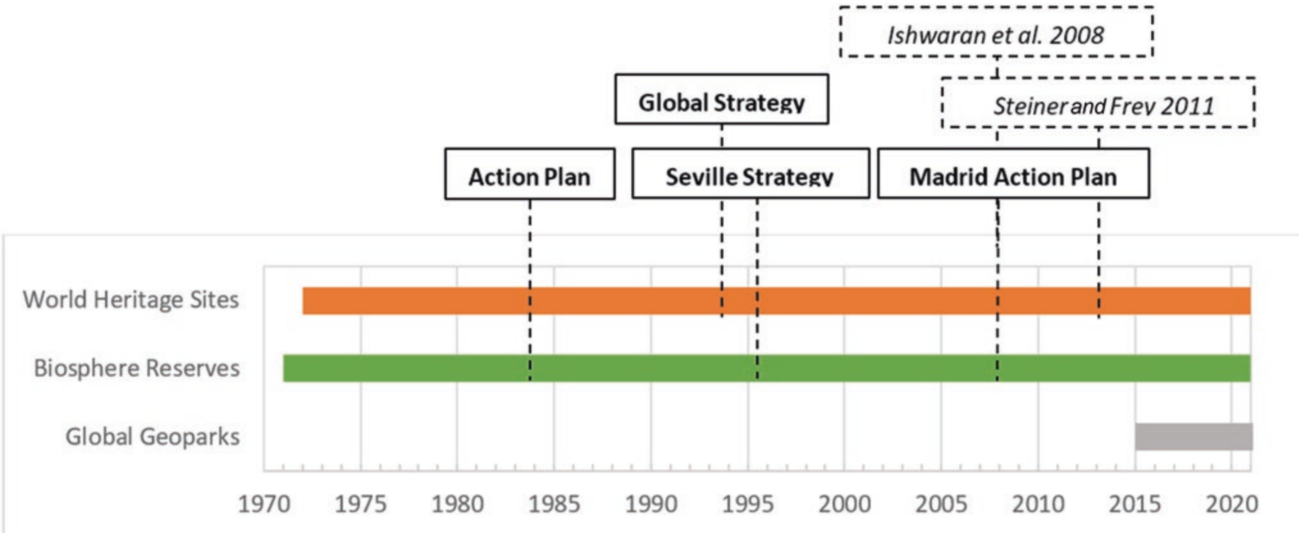


Fig. 13.1 UNESCO Global Geoparks, World Heritage and MAB Programme and significant global policies and scientific investigations

areas (Ishwaran et al. 2008). As a response to emerging challenges, the Madrid Action Plan comprises objectives to adapt and mitigate climate change, to counteract threats associated with rapid urbanisation and to interlace individual activities of biosphere reserves with the Millennium Development Goals (UNESCO 2008). Every 10 years, a biosphere reserve is reviewed. Over the last decades, more than 55 biosphere reserves around the globe lost their status (UNESCO 2019a).

13.1.4 UNESCO Global Geoparks

What started as national initiatives in Europe and China, which founded the Global Geopark Network (GGN) in 2001, became officially the network of UNESCO Global Geoparks during the 38th General Conference in 2015 (Henriques and Brilha 2017). Global Geoparks are defined as unified geographical areas with sites and landscapes of international geological significance. Here, the protection of nature and the development of sustainable forms of economic activities are at the forefront. Although it is the youngest of the UNESCO networks, there are already 169 global parks listed in 44 countries (UNESCO 2021b).

The unequal distribution of UNESCO World Heritage Sites and Biosphere Reserves is shown in several graphs, statistics and maps (Ishwaran et al. 2008; Steiner and Frey 2011). In this study, cartograms are used to visualise and analyse the global distribution in several periods. In Sect. 13.2, the data preparation and creation of cartograms with the open-source software Quantum GIS (QGIS) is explained. Subsequently, the distribution of Global Geoparks illustrates the usage of cartograms. In Sect. 13.3, the statements of the cartograms are compared to trends mentioned by Steiner and Frey (2011) for the heritage sites and Ishwaran et al. (2008) for biosphere reserves. The cartogram for the last decade is used to check if historical trends in the distribution reduced, stagnated or continued.

13.2 Data and Methods

This study focuses on the spatial distribution of UNESCOs World Heritage Sites, Biosphere Reserves and Global Geoparks. Nowadays, spatial analyses are performed with the help of geographical information systems (GIS). A GIS is a software to collect, manage, analyse and present geodata. Geodata are data with a spatial allocation mainly realised using geographic coordinate systems. Spatial information is used in a broad field of applications from exploring global change to planning and marketing. Experts estimate that in local administration processes, up to 80% of all data have a spatial reference (Garson and Biggs 1992). In general, geodata is separated into raster data like satellite imagery and vector data like the position of a UNESCO site. Furthermore, vector data are differentiated by polygon, line and point features regarding the spatial object they are representing. A polygon represents areas like the core or buffer zone of a biosphere reserve. A line represents a linear object like a river, and a point represents a specific spot like a monument. Whether a spatial object like the temples of Angkor Wat in Cambodia is properly represented by a polygon or a point feature depends on the scale of the analysis. On a local scale, a polygon feature is useful to represent the size and shape of a site like Angkor properly. However, to investigate the spatial distribution on a global scale, the location of a site like Angkor as a point feature is sufficient.

13.2.1 Data

A common challenge working with GIS is a lack of easily and freely accessible geodata. With the help of political guidelines like the Infrastructure for Spatial Information in Europe (INSPIRE) or open-source projects like OpenStreetMap, data availability improved significantly during the last decades (Crompvoets et al. 2004; Goodchild and Li 2012). Especially open-source data improved data availability and boosted the opportunities of spatial analysis (Zhu et al. 2019). However, availability for statistical global geodata, like inhabitants per country, is still diffuse or missing.

As mentioned above, the aim of this study is the spatial analysis of UNESCO World Heritage Sites, Biosphere Reserves and Global Geoparks over time. The data procurement used in this work is an example of collecting geodata from different sources with different methods. The preparation and analysis of the data was carried out in the open-source GIS software QGIS. Before using the data for analysis or map making, it is important to check their quality. The data must be complete, precise, accurate and consistent. Accurate in this case means geometrically accurate and the entries in the attribute table of each object have to correspond to the real-world entities. Data with low quality can lead to consequential failures in the analysis (Heywood et al. 2011). For the analysis in this work, the dataset needs to include the UNESCO sites as points with additional information about the year of designation.

UNESCO itself provides datasets of the 1221 world heritage sites with longitude, latitude and date of designation for each site on its website (last downloaded May 13, 2021). Tables with coordinates can be plotted in a GIS and exported as geodata files.

Up to now, the datasets of the MAB Biosphere Reserves are collected by the MAB Programme. These data also need to be transformed into geodata files within a GIS as mentioned before. The latest state of the biosphere reserves data for this work refers to April 15, 2021. The MAB Programme includes 11 transboundary biosphere reserves. UNESCO is counting the sites on a national level, and hence, two points represent one transboundary site. Each point feature belongs to one country, which is involved in the transboundary biosphere reserves. For this reason, the total numbers of our dataset and those from Ishwaran et al. (2008) differ in the first two time periods.

The difference in the total number of world heritage sites and biosphere reserves in the third period can be explained by different deadlines for periods in both datasets. However, general trends of the distribution in both datasets are similar. As both datasets are official geodata from UNESCO, it is expected that those are of high quality.

Geodata of the UNESCOs Global Geoparks are not accessible yet. However, the UNESCO published a map of global geoparks in 2020 (Source: http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/unesco-global-geoparks/list-of-unesco-global-geoparks/, last downloaded 30th of March 2021). Maps with a coordinate grid and a projection can be georeferenced in a GIS with the "Georeferencer Plugin". Therefore, distinctive points on the map were set and provided with coordinates of an already projected reference map. The georeferenced map then appears as a new raster layer. In this case, the "UNESCO Global Geoparks 2020 Map" was georeferenced. Subsequently, the global geoparks can be digitised as a new vector dataset. Therefore, an empty dataset was created within the QGIS project. The editing function had to be started to add a new point object to the dataset. Afterwards, new objects were added by clicking on the displayed georeferenced map of the UNESCO Global Geoparks. Additionally, new columns in the attribute table were added. Using the official list of UNESCO Global Geoparks (UNESCO 2021b), the name and the founding year of each park were added manually.

To investigate the distribution of UNESCO sites and the imbalance of their distribution described by Steiner and Frey (2011) and Ishwaran et al. (2008), global data with regional reference is needed. The United Nations Statistics Division defined the United Nations (UN) geoscheme on a continental, regional and subregional scale (Department of Economic and Social Affairs Statistics Division 1999). The UN subregional scales are an appropriate level of detail to show potential continental and intracontinental imbalances. The UN subregions dataset is freely accessible under public domain by the platform Natural Earth (see Fig. 13.2). Based on the timeframes mentioned in Steiner and Frey (2011) and Ishwaran et al. (2008), the datasets of the heritage sites and biosphere reserves were divided in three and four datasets, respectively (see Fig. 13.1). For the heritage sites, each dataset contains the sites established between 1972–1993, 1994–2010 and 2011–2021 (see Fig. 13.1). Therefore, the sites designated within three timeframes were "selected by attribute" and saved as a new vector file. The same was done with the biosphere reserves for the timeframes 1971–1985, 1984–1995, 1996–2007 and 2008–2021.

Finally, the number of heritage sites, biosphere reserves and global geoparks was merged to the 20 UN subregions (see Table 13.1). With the "count points in polygon" tool, the number of sites within a polygon is counted and added to a created column in the attribute table of the dataset. The same was carried out for the new created datasets based on the timeframes mentioned above. All further analyses were carried out with the dataset of the UN Global Geopark.

Figure 13.2 shows the global distribution of UNESCOs World Heritage Sites, Biosphere Reserves and Global Geoparks. In the background of these 2.096 UNESCO sites, Fig. 13.2 shows the borders of the UN subregions.

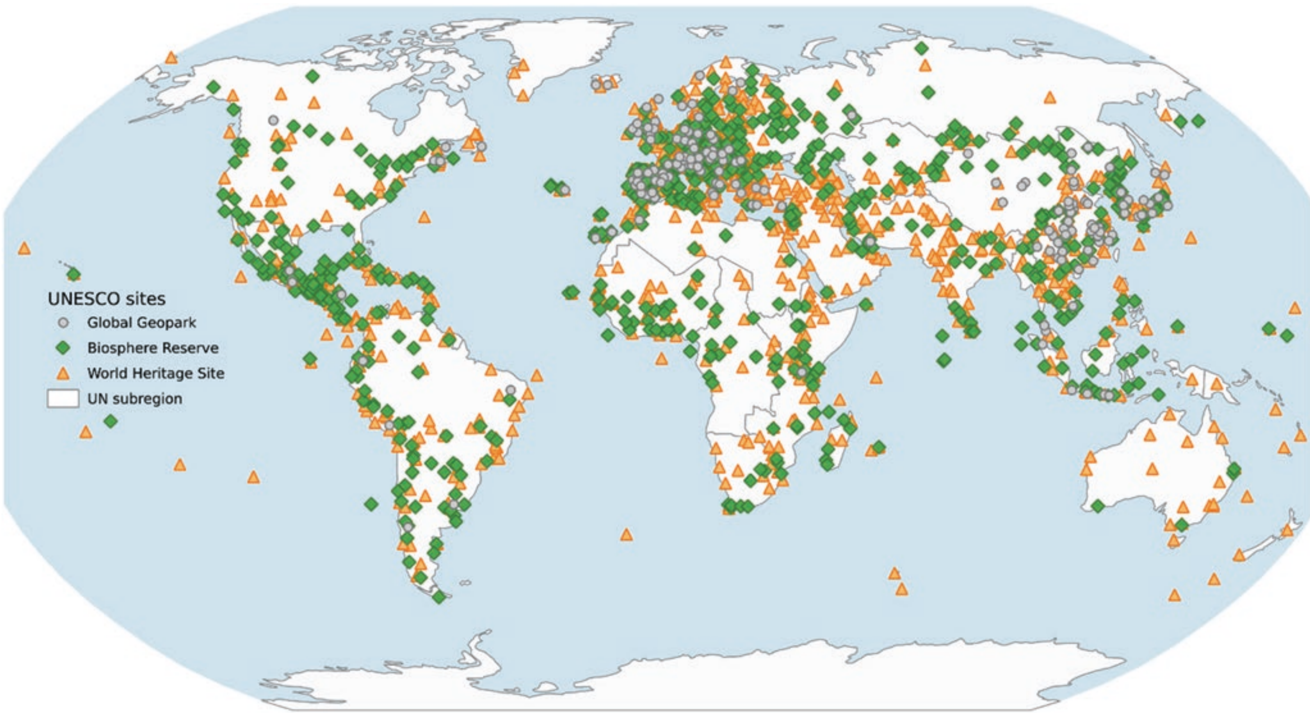


Fig. 13.2 Map of the global distribution of UNESCO Global Geoparks, Biosphere Reserves and World Heritage Sites within the UN subregions

Table 13.1 Total number of designated UNESCO World Heritage Sites during the three periods 1978–1993, 1994–2010 and 2011–2021 based on the datasets used in this chapter

UN subregion	1978–1993	1994–2010	2011–2021	Total
Eastern Africa	21	17	5	43
Middle Africa	6	3	5	14
Northern Africa	27	9	3	39
Southern Africa	0	10	4	14
Western Africa	14	10	5	29
Caribbean	4	10	3	17
Central America	22	26	6	54
Northern America	27	8	10	45
South America	27	36	9	72
Central Asia	2	10	1	13
Eastern Asia	14	53	30	97
South-eastern Asia	12	18	12	42
Southern Asia	41	21	21	83
Western Asia	26	29	30	85
Eastern Europe	35	44	12	91
Northern Europe	24	41	9	74
Southern Europe	62	77	20	159
Western Europe	34	65	21	120
Australia and New Zealand	12	8	2	22
Melanesia	0	6	2	8
	410	**501**	**210**	**1121**

13.2.2 Methods

13.2.2.1 Maps and Their Difficulties

Maps are projected, generalised and simplified representations of the world and one of the most important geographic media. They represent natural and man-made environments from local to global scales. Furthermore, maps can also show the distribution of statistical values like income, age or the unequal distribution of wealth (through indicators like the Gini coefficient). They are used for orientation, planning, analysis, advertisement and propaganda (Monmonier 1996). Maps have "power" as they influence the way humans look at the world (Glasze 2009). World maps are mostly oriented north-south and display Europe in their centre (Hodgkinson 1991). This Eurocentric view on the world is supported by most map projects, which show areas in the north like Europe, Greenland or North America disproportionately large in comparison to Africa (Hodgkinson 1991; Lapon et al. 2020). On maps based on the common Mercator projection, Greenland is illustrated as almost the size of Africa, although it is not even a tenth of the size (c.f. Lapon et al. 2020). Those projections are needed to map the 3D globe on a plain surface (Monmonier 1996). This creates a distortion of the maps in the direction of the poles, and these areas are clearly stretched and shown larger than they really are. But those maps also reproduce a Europe-centred worldview (Rose-Redwood et al. 2020) and downplay the meaning of Africa. Maps facing south or maps with East Asia in the centre confuse people. However, they are useful to show that maps and space are man-made. Monmonier (1996) described various ways for cartographers to lie with maps. Some of those lies are needed, as a map can only show a generalised and simplified representation of the world. But other tricks are used for advertisement or even propaganda. For example, the border conflict between India and Pakistan about the Kashmir region is also illustrated in maps. Both parties published maps, in which Kashmir is part of their country (Wagner & Stanzel 2020).

Colour schemes in maps are needed for the usability but can lead to misunderstandings. The UN usually uses the equal-area Robinson projections for their maps. The advantage of those maps is that the area of a country on the map corresponds to the real areas. As a consequence, the shape and location of countries need to be adjusted. Figure 13.3a shows such a world map with the UN subregions coloured, based on the number of UNESCO Global Geoparks within. As more parks are located within a region, the darker the colour is. In Europe, there are nine times more geoparks than in Northern, Central and Southern America together. On the other hand, these UN subregions are almost ten times smaller than the American continent and therefore take up less space on the map. Small areas get less attention than large areas (Monmonier 1996). Unintentionally, this map played down the inequality between those regions, due to area size and colour scheme. Many problems with maps are based on the fact that areas are only displayed according to their position on the globe.

13.2.2.2 Cartograms

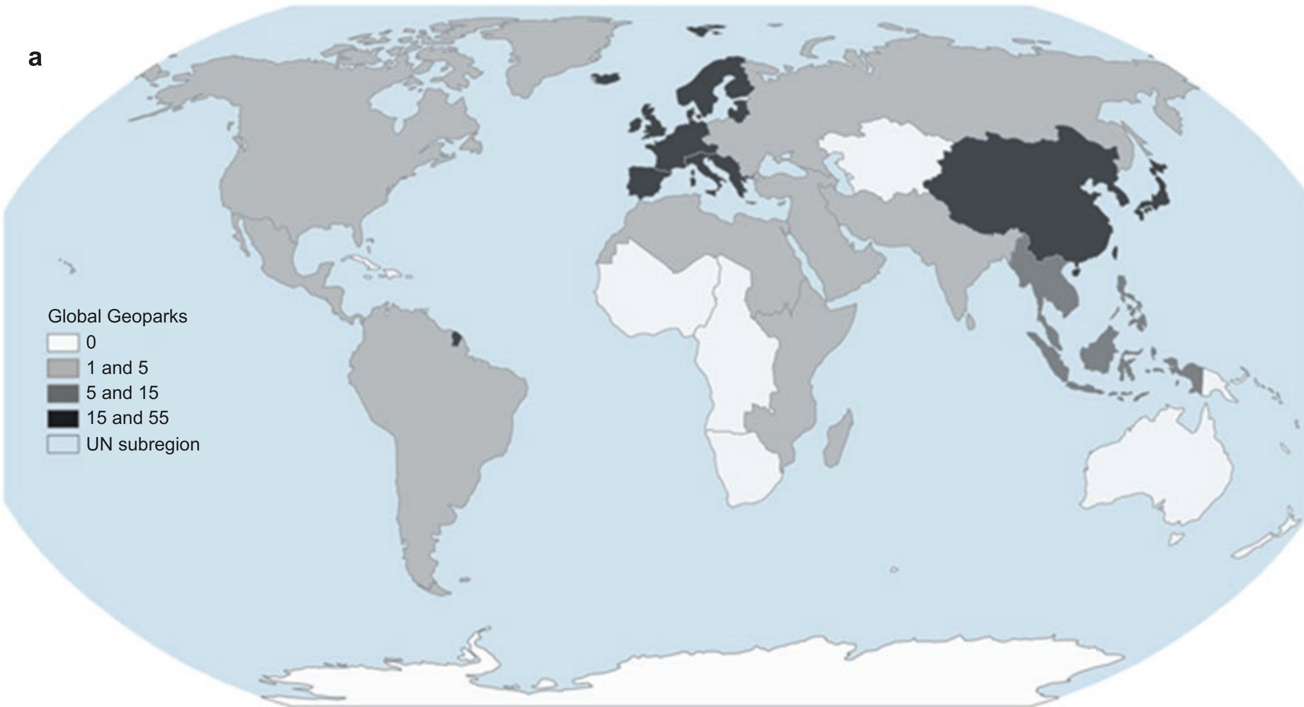
Cartograms or anamorphic maps try to overcome the problem mentioned above. They are "value-by-area-representations" of parts of the globe (Han et al. 2017: 3). In cartograms, spatial properties are associated with statistical values like income or in this case the number of Global Geoparks within a specific area. If the area of a polygon, e.g. an UN subregion, is disproportionately large compared to a related statistic value, e.g. the number of Global Geoparks, the area of the polygon shrinks in the cartogram and vice versa. Figure 13.3b presents a cartogram which illustrates the uneven distribution of Global Geoparks in 2021. The map shows that nearly half of all global geoparks are in Europe. However, Europe only covers 5% of the land surface of earth. Simultaneously, Fig. 13.3b shows a slight shrinking of African UN subregions because they contain only two global geoparks, although this continent covers about 20% of the land surface.

13.2.2.3 How to Generate Cartograms

The creation of cartograms like the one in Fig. 13.3b is possible for any positive statistical value. On the World Mapper website,[1] more than 700 cartograms (mostly based on socioeconomic indicators) show the world's inequality (Hennig 2018). While the first cartograms were hand-drawn, modern geographic information systems (GIS) can easily compute them (Hennig 2018). Nowadays, open-source GIS like QGIS offer a broad variety of spatial applications. The QGIS plugin "cartogram" enables users to generate contiguous cartograms based on areas represented by polygon layers, in this case UN subregions. The plugin is based on an iterative algorithm from Dougenik et al. (1985). The algorithms distort polygons depending on the difference of the normalised size of the polygon to a normalised statistical value of the polygon. If the difference is positive, the polygon gets enlarged. A negative difference minimises the polygon.

The distortion of polygons also depends on the distance and the difference of the normalised size and the normalised statistical value of the other polygons. If any polygon contains a zero or *NULL* value, the algorithm creates suitable replacement values. This falsifies the map minimally but allows it to render the map anyway. Thereby the shape of the polygons gets distorted by the algorithm, but the topology remains. The topology describes the neighbourhood relationships of polygons which are preserved by the falsification, and hence, contiguous areas remain.

The algorithm deforms the polygons in iterative steps, and this fastens the algorithm and helps remain the topology. In every step, the difference between the normalised size and the normalised value of every polygon gets smaller. If it reaches zero for every polygon, the algorithm stops. Finally, the ratio of the size of two polygons equals the ratio of the selected statistical value. This duration of the procedure depends on the number of polygons (Dougenik et al. 1985). The algorithm can lead to unreadable maps due to its distortion. For better performance, it is possible to select the numbers of iterations in the QGIS plugin. The selected number of iterations in the plugin leaves a certain leeway to the cartog-



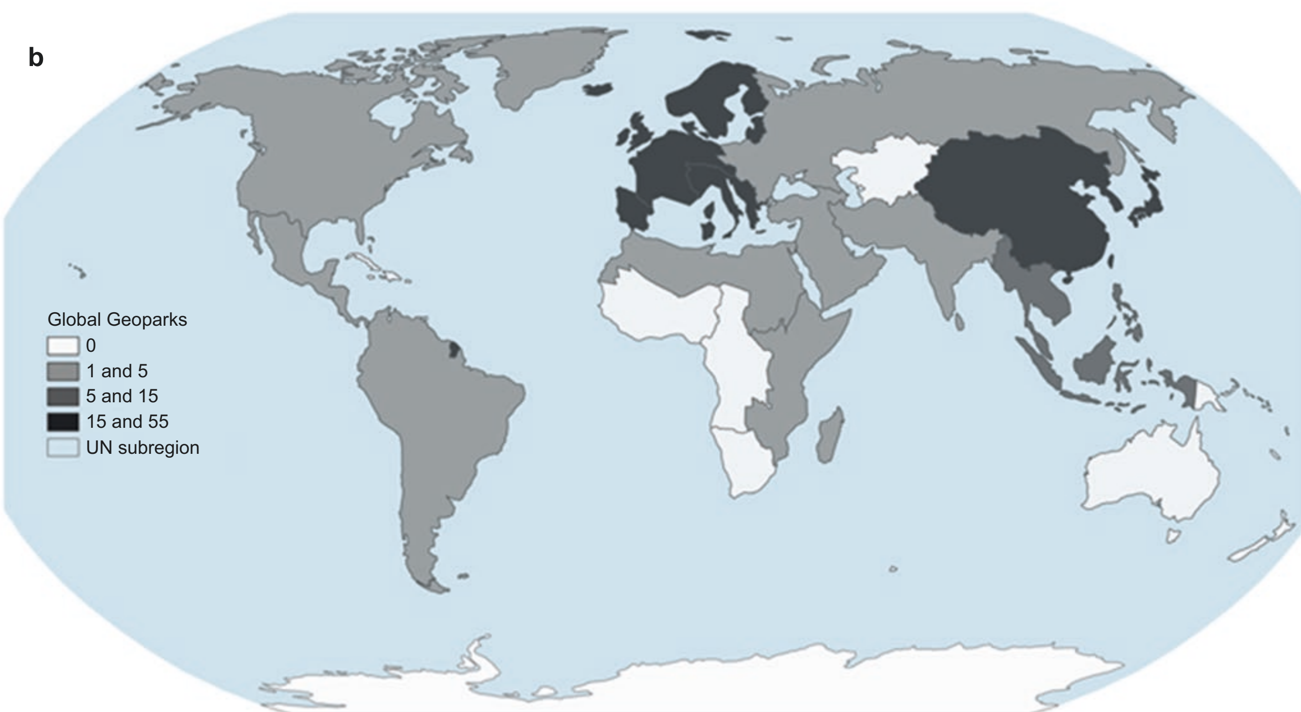


Fig. 13.3 (**a**) Map of the global distribution of UNESCO Global Geoparks within the UN subregions. (**b**) Cartogram of the global distribution of UNESCO Global Geoparks within the UN subregions

raphers, as the distortion in most cases grows with every iteration. For this reason, the appearance of a cartogram depends on statistical values and the numbers of iterations. Nevertheless, cartograms are very useful to show trends and spatial patterns. For the cartograms in this chapter, 5–20 iterations were performed. Experiments showed that cartograms based on an equal-area projection perform as good as equidistant projections (Han et al. 2017). Due to the topic, all maps in this chapter are based on the equal-area Robinson projection, also used for official maps of the UN.

Gastner and Newman (2004) developed an alternative algorithm for cartograms based on differential equations. This algorithm also preserves the topology of the polygons and allows the users to balance between large and low distortions. The cartogram geoprocessing tool available in ArcGIS is based on this algorithm. The cartograms in the World Mapper Project are based on a new version of this algorithm (Gastner et al. 2018; Hennig 2019). However, due to the licensing of ArcGIS, the tool is not freely available.

13.2.2.4 Interpreting a Cartogram

Cartograms distort commonly known shapes of polygons, like continents, and therefore should amaze and puzzle the readers, forcing them to ask the right questions (Hennig 2013). By doing this, space-related values, which are not necessarily related to the special distribution of an area, can be highlighted. While cartograms on a national level are difficult to read, cartograms on a continental level have a good usability. They are particularly useful when you need to compare larger areas such as UN subregions (Han et al. 2017).

Place and space are important geographical concepts. They can help ask specific geographical questions and organise information to find explanations for geographical problems (Maude 2020). Every place, from houses to cities to UN subregions, has characteristics which give those places a man-made meaning (Maude 2020). In cartograms, the known shape of places is distorted depending on its meaning. So cartograms do not show places based on their position on the globe. However, they show that the meaning of a place is not depending on its actual size and that places are man-made. In a cartogram, the specific value of every polygon influences the distortion of the others. It is possible to analyse the meaning of a place and its importance in space using cartograms. By considering different time scales, it is possible to analyse their change of importance over time.

Four steps are necessary to interpret a cartogram or thematic map: orientation, description, summary and discussion/conclusion (c.f. Hennig 2019). The first step is to clarify which part of the world can be seen in the cartogram and depending on which value the polygons are distorted. The cartogram in Fig. 13.3b is a world map of the UN subregions. Those regions are represented as polygons and are distorted based on the number of UNESCO Global Geoparks within. Additionally, the UN subregions are coloured based on the number of UNESCO Global Geoparks. For a better understanding of the cartogram, additional material is helpful. In this case, the reader needs to know what the UN subregions and UNESCO Global Geoparks are (see Sects. 13.1 and 13.2). For a proper description of the cartogram, it is necessary to compare it with a map of the same area with the same projection (for all cartograms in this section, use Fig. 13.3a). It is possible to recognise even small distortions in the cartogram using this comparison. The polygons representing Southern, Western and Northern Europe as well as Eastern and South-Eastern Asia increased in the cartogram, while all other polygons representing the other regions shrank.[1] In summary, there are two hot spots of global geoparks, one in Europe and the other one in Eastern Asia. Finally, the distortion should be discussed and a conclusion drawn. The summary can be used to make assumptions, but additional sources are required to check them. Otherwise, the cartogram can lead to misunderstandings.

The distortion towards the polygons of East Asia, South-Eastern Asia and European subregions is consistent with the dark grey colouring of those areas, displaying many geoparks within those regions. The number of geoparks in Northern Africa and Northern America is similar. However, the distortion of Northern Africa seems larger, as the shape of the region is heavily deformed, while North America only shrinks. This effect is due to the proximity to European subregions. In the European subregions, there are disproportionately many global geoparks in comparison to their land areas. Therefore, European subregions expand considerably and influence the distortions of polygons in its proximity to a higher extent than polygons at a greater distance. There is no UNESCO Global Geopark in Southern Africa and only one in Eastern Africa. Both regions shrank to a similar extent. The cartogram displays this minor difference better than the selected colour scheme with four classes. In summary, the cartogram shows that there is a disproportionately large number of UNESCO Global Geoparks in the European subregions, Southern Asia and Eastern Asia compared to their area, and vice versa for all other subregions.

UNESCO Global Geoparks are landscapes of international geological value and manage to combine protection, education, economy and sustainable development (Henriques and Brilha 2017; UNESCO 2021b). The shape of the cartogram led to the question of why there are so many more global geoparks in European subregions and Eastern Asia than in the rest of the world. An explanation for this imbalance is the history of global geoparks. The first geoparks were established in 1980 in Germany, without being part of a UNESCO programme. In 2000, a network of geoparks was founded in Europe and China, leading to the first Global Geopark Network (GGN) in 2001. Finally, in 2015, the UNESCO Global Geopark Programme started with most of the GGN geoparks. Therefore, the global imbalance of global geoparks is the result of national and international bottom-up initiatives, which try to promote unique geological landscapes (Henriques and Brilha 2017). In the next sections, the global distribution of UNESCO World Heritage Sites and

[1] For better readability, the expression "in the cartogram the polygon representing Eastern Europe shrank or gets bigger" was simplified to "in the cartogram Eastern Europe shrank or gets bigger".

Biosphere Reserves over different time scales is analysed with the help of cartograms.

13.3 Results and Discussion

In this section, the results for the investigated time periods are presented. On the one hand, the cartograms are a visualisation of the imbalances during the periods mentioned in Sect. 13.1 (see Fig. 13.1). Cartograms were used to find out how the imbalance continues since 2011 for the world heritage sites and since 2008 for the biosphere reserves. The interpretation of the cartograms must consider the total number of sites designated during a specific phase.

13.3.1 World Heritage Sites

Since the adoption of the UNESCO World Heritage Programme, the distribution of world heritage sites has become a major subject of concern. The global strategy tried to achieve a more balanced designation of sites in 1994. Steiner and Frey (2011) evaluated the impact of the global strategy with several statistical indicators. None of the examined indicators showed a more balanced distribution after the designation of the global strategy. Conversely, the statistical indicators presented an acceleration of growth in European countries and, therefore, an even stronger imbalance compared to the phase between 1972 and 1993 (Steiner and Frey 2011).

Figure 13.4a shows the spatial distribution of world heritage sites for the years 1972 to 1993. The UN subregions with the most designated number of sites during this period are Southern Europe, Southern Asia and Western Europe (see Table 13.1). This selection shows the imbalance towards European subregions. The cartogram in Fig. 13.4a visualises this bias. This distortion occurs due to the combination of the small land area of Europe and the high number of designated world heritage sites within Western and Southern Europe between 1972 and 1993 (see Table 13.1). Western and Southern Europe together designated 96 sites (23%), and they cover less than 4% of the land area. These two European subregions designated more than twice as many sites as Southern Asia, which ranked second in this period with 41 designated sites (see Table 13.1). Accordingly, the area of Southern Asia expanded as well (see Fig. 13.4a). Alongside, a sequence of subregions like Southern America or Eastern Asia designated between 25 and 35 world heritage sites and shrank in the cartogram (see Fig. 13.4a). Furthermore, subregions like the Caribbean, Southern Asia, Melanesia and Southern and Middle Africa designated less than ten or even zero world heritage sites and shrank in the cartogram substantially.

Figure 13.4b shows the world heritage sites designated between 1994 and 2010 and, hence, the phase after the declaration of the Global Strategy in 1994 (see Fig. 13.1). The number of designated sites in Eastern Asia increased by a factor of four during this phase. Therefore, Eastern Asia showed the strongest growth. However, Southern and Western Europe designated even more sites in total, respectively (see Table 13.1). The UN subregions with the most designated sites between 1994 and 2010 are Southern Europe, Western Europe, Eastern Asia, Eastern Europe and Northern Europe. This strong bias towards European subregions is illustrated in Fig. 13.4b and was statistically described by Steiner and Frey (2011). During this phase, 183 world heritage sites or rather 36% of all sites were designated within the subregions Western and Southern Europe (see Table 13.1).

Since Steiner and Frey (2011) investigated the imbalance of world heritage sites, the maximum designated number of sites per subregion decreased due to the shorter period. However, the spatial distribution changed for the phase between 2011 and 2021 (see Fig. 13.4c). Figure 13.4c shows the highest number of designated sites in Eastern Asia, Western Asia and Southern Asia (see Table 13.1). These three subregions cover 39% of the designated sites during this phase. This shows a tendency of catching up according to the world heritage sites for these UN subregions. However, Western Europe and Southern Europe rank among the subregions with most designated sites (20%), which decelerates the catching-up process of Asian subregions. Furthermore, Southern American and Eastern Asia designated less world heritage sites and shrank.

The cartograms in Fig. 13.4 show the distortion of UN subregions due to the designation of world heritage sites within the specific phases (see Fig. 13.1). Figure 13.4a, b visualises the already known bias towards European subregions, especially towards Southern and Western Europe. Figure 13.4b clearly visualises the strong increase of world heritage sites in European subregions and, hence, the ineffectiveness of the Global Strategy (Steiner and Frey 2011, c.f.). On the contrary, Fig. 13.4c shows the catching up of designated sites in Western, Southern and Eastern Asia. Simultaneously, Western and Southern Europe also designated many world heritage sites, which led to a de facto stagnation of this imbalance. The mentioned catching-up process reduced the proportion of Northern, Western and Southern European subregions from 33% in 2010 to 31% in 2021 (see Table 13.1). This shows that the high number of designated sites in Eastern, Southern and Western Asia illustrated in Fig. 13.4c only had a marginal impact on a more balanced designation of world heritage sites. Additionally, other UN subregions, i.e. Australia and New Zealand or Northern Africa, decreased during all phases, and the imbalance towards them increased. The shorter temporal range of phase

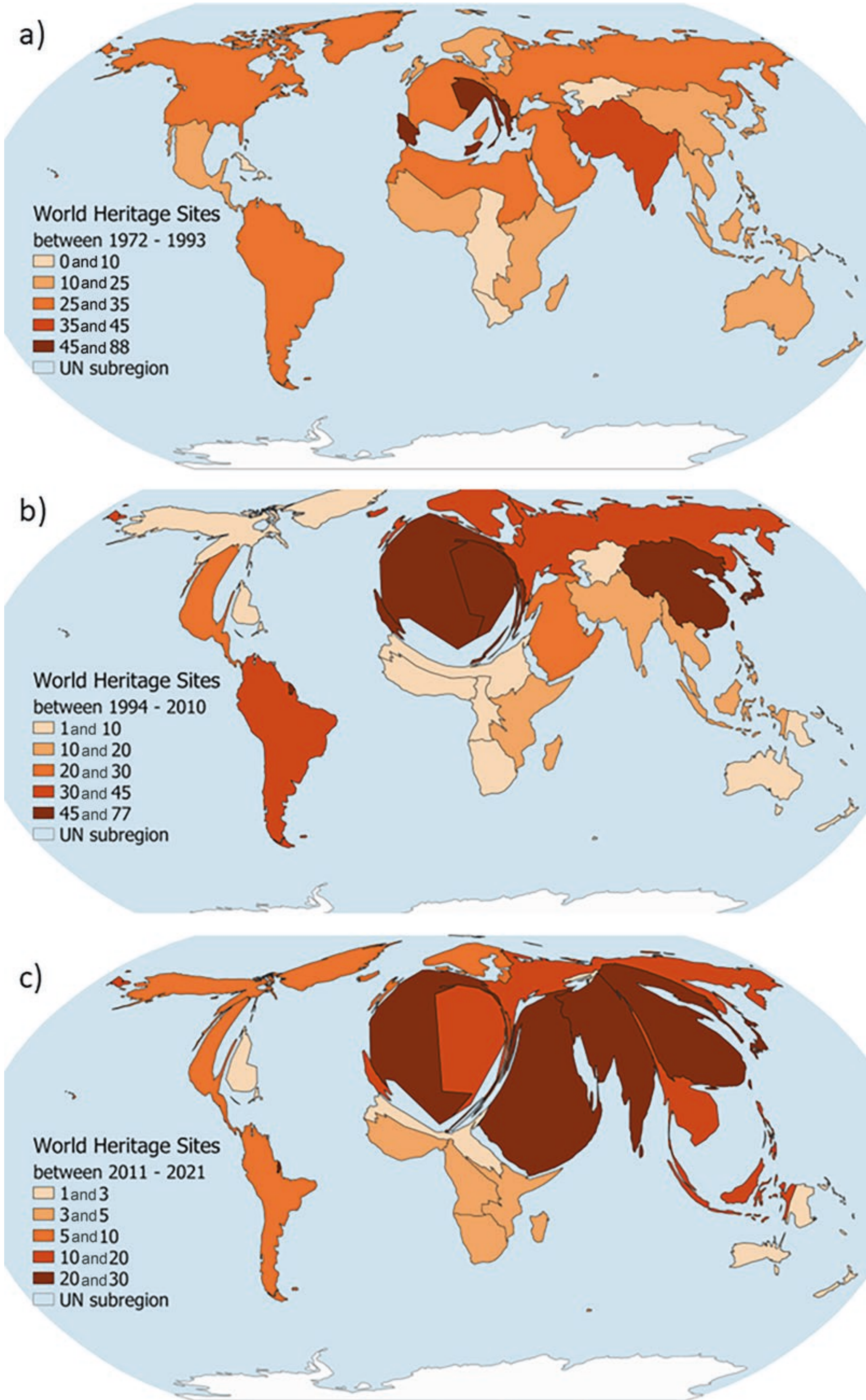


Fig. 13.4 Cartogram of the global distribution of UNESCO World Heritage Sites within the UN subregions (**a**) between 1972 and 1993, (**b**) between 1994 and 2010 and (**c**) between 2011 and 2021

2011 to 2021 compared to the two previous phases and, hence, the lower total number of world heritage sites must be kept in mind in the comparison of the table and the cartograms. Nonetheless, Fig. 13.4c illustrates a trend which occurred during the last 10 years. In general, the cartograms and Table 13.1 suggest that the Global Strategy was and is up to now inefficient.

13.3.2 Biosphere Reserves

Currently, more than 700 biosphere reserves are part of the MAB Programme. The MAB Programme was designated in 1971 and is nowadays established in all UN subregions. The programme experienced different development phases (see Fig. 13.1) (UNESCO 2019b). In this work, the biosphere reserve phases classified by Ishwaran et al. (2008) were used. The first phase includes the period from the foundation of the MAB Programme in 1971 to the year 1984. The second phase started in 1985 with the Action Plan for Biosphere Reserves, which underlined the vision of biosphere reserves as protected areas and their role to support sustainable development. The biosphere reserves designated between 1996 and 2007 mark the third phase due to the Seville Strategy. Additionally, a fourth phase was added to obtain a trend of the designated biosphere reserves since Ishwaran et al. (2008) published their inventory.

The spatial distribution of biosphere reserves designated during the first phase can be seen in Fig. 13.5a. As the colour scheme shows, most reserves were designated in Southern America, Northern America and Eastern Europe. While the first subregion gets bigger, the others shrink in the cartogram, showing that their number of biosphere reserves in relation to their area is small. Southern Europe and Southern Asia are in the upper mid-range (see Table 13.2). In those subregions, the number of biosphere reserves in relation to their area is high. The areas in the two classes with the lowest amount of biosphere reserves do not show a clear tendency; while Western Europe, Northern Europe and Central America grew, Central and Eastern Asia shrank.

Especially Northern, Western and Southern Europe are enlarged and distorted. In those areas, 20% of all biosphere reserves were designated during the first period, and they cover less than 5% of the global land area. Ishwaran et al. (2008) investigated that more than 50% of all biosphere reserves in this phase were designated in Northern America and Europe. They state the inequality in the distribution of the biosphere reserves towards the most industrialised regions of the world (Ishwaran et al. 2008). The cartogram in Fig. 13.5a confirms this statement by showing that especially in European subregions, there are disproportionately many biosphere reserves in relation to their areas. Considering that 16 biosphere reserves designated during this period in Northern America lost their status in 2017, the cartogram understates the dominance of Northern America in this phase. As Russia, which covers about 11% of the land area, belongs to Eastern Europe, this polygon shrank, although 17% of all designated reserves are in this subregion.

Nineteen percent of all biosphere reserves were designated in Asia and Pacific during the first phase, and this area covers more than 40% of the land area, showing the inequality in the distribution of the biosphere reserves. Nevertheless, the subregions in both continents do not show the same tendency in distortion. Table 13.2 shows that most of the biosphere reserves in Asia within this phase are in Southern (12) and South-Eastern Asia (11). While the relative number of biosphere reserves in Asia shows a clear global inequality (Ishwaran et al. 2008), the cartogram in Fig. 13.5a shows another inequality in the distribution within the Asian UN subregions.

Figure 13.5b shows the cartogram based on the number of biosphere reserves added to the subregions between 1985 and 1995. Most reserves were designated in Eastern and Western Europe, both subregions enlarged in the cartogram. All three subregions with five to ten designated biosphere reserves enlarged in the cartogram, except Northern America, which shrank. All subregions in Africa shrank regardless of their number of reserves. Southern and South-Eastern Asia shrank. In Southern Asia, no further biosphere reserve was established, while two in South-Eastern Asia were declared between 1985 and 1995.

In general, the second phase between 1985 and 1995 was a period of transition with significant reflection and refinement of the concept of biosphere reserves. This refinement process is reflected in the lower number of designated biosphere reserves (Ishwaran et al. 2008). However, the general trend of Western dominance further increased, as about 65% of all designated reserves are in North America and Europe. While still less than 10% of the reserves were designated in Asia, the unequal distribution within the Asian subregions mentioned for the first phase changed. Eastern Asia designated nine biosphere reserves in the first phase and seven in the second. Nonetheless, the related polygon shrank in the first period and enlarged in the following. This effect can be explained with the lower total number of designated biosphere reserves in the second period, as the distortion of a polygon depends on the total amount of reserves (Sect. 13.2). Between 1984 and 1995, a total of 83 reserves were designated worldwide, about 8% of them in Eastern Asia. Between 1971 and 1984, a total of 186 biosphere reserves were designated worldwide, but only about 4% of them in Eastern Asia (see Table 13.2).

In the post-Seville phase, between 1996 and 2007, an exceptionally high number of 214 biosphere reserves were designated. The focus in this period was to combine biodi-

Table 13.2 Total number of designated UNESCO Biosphere Reserves in the MAB Programme during the four periods 1976–1985, 1986–1995, 1996–2007, and 2008–2020 based on the datasets used in this chapter

UN subregion	1976–1985	1986–1995	1996–2007	2008–2020	Total
Eastern Africa	9	2	7	12	30
Middle Africa	8	1	0	2	11
Northern Africa	7	3	7	5	22
Southern Africa	0	0	5	6	11
Western Africa	10	2	9	14	35
Caribbean	1	3	3	4	11
Central America	7	10	30	14	61
Northern America	23	10	9	3	45
South America	21	8	19	13	61
Central Asia	3	1	1	12	17
Eastern Asia	9	7	23	24	63
South-eastern Asia	11	2	8	21	42
Southern Asia	12	0	7	15	34
Western Asia	0	0	8	6	14
Eastern Europe	33	13	29	17	92
Northern Europe	5	3	2	12	22
Southern Europe	18	5	33	37	93
Western Europe	8	13	10	13	44
Australia and New Zealand	1	0	2	1	4
Melanesia	0	0	2	0	2
	186	**83**	**214**	**231**	**714**

versity conservation and socio-economic growth in a sustainable way in the biosphere reserves. Eastern Asia, Central America, Southern Europe and Eastern Europe established the most reserves in this period. While Eastern Asia, Central America and Southern Europe enlarged in the cartogram in Fig. 13.5c, Eastern Europe shrank, as in the periods before. All African subregions, Northern America, Central Asia, Southern Asia, Australia and New Zealand shrank, while Western and Northern Europe grew in the cartogram.

Still, North America, Central America and Europe together designated more than 50 biosphere reserves (Ishwaran et al. 2008). The focus in America was mainly on Central America; the related polygon tripled in size, while Northern America shrank. In Southern, Western, and Northern Europe, still disproportionately many biosphere reserves in relation to the area were designated. In this period, the trend of the Western dominance was reduced. However, the trend in Asia changed. The number of designated biosphere reserves in Eastern Asia was also disproportionately high in relation to its area. Furthermore, the number of designated biosphere reserves in Western Asia, Southern Asia and South-Eastern Asia grew.

The fourth phase marks the period between 2008 and 2020. In 2008, the Madrid Action Plan comprised objectives like climate change mitigation and adaptation or responses to urbanisation processes. The cartogram in Fig. 13.5d can be used to prove if major trends of the distribution of biosphere reserves illustrated by Ishwaran et al. (2008) and the cartograms in Fig. 13.5a–c from 1971 to 2007 continue till 2020. The total numbers of designated biosphere reserves in both datasets differ for the periods. However, they show the same trends.

Since the beginning of the MAB Programme, most of the biosphere reserves were designated in the Western world. All cartograms clearly show the dominance of Central America and Southern, Western and Northern Europe, but they also show that the number of biosphere reserves in Northern America and Eastern Europe is disproportionately low in relation to their area. This effect can be explained by the fact that Russia, Canada and the United States are the three largest countries in the world, which lie in those two subregions. Additionally, North America lost more biosphere reserves than any other subregion. The cartogram in Fig. 13.5d shows that this trend in the Western world clearly continues but is toned down. Between 2008 and 2020, 40% of all biosphere reserves were designated in the Western world. Australia and New Zealand are the exceptions for the Western world, as the number of UNESCO Biosphere Reserves in those countries is always low. There are only four biosphere reserves in Australia (see Table 13.2). Consequently, the polygons of Australia and New Zealand shrank in all four periods.

The number of biosphere reserves in Southern America is growing steadily. In all three periods, the cartogram displays this trend as Southern America always gets bigger. However, while more than 10% of all established reserves are in South America during the first two phases, the percentage is below 10% in the other periods (see Table 13.2). Figure 13.5c shows this reversing trend as Southern Asia shrank in size

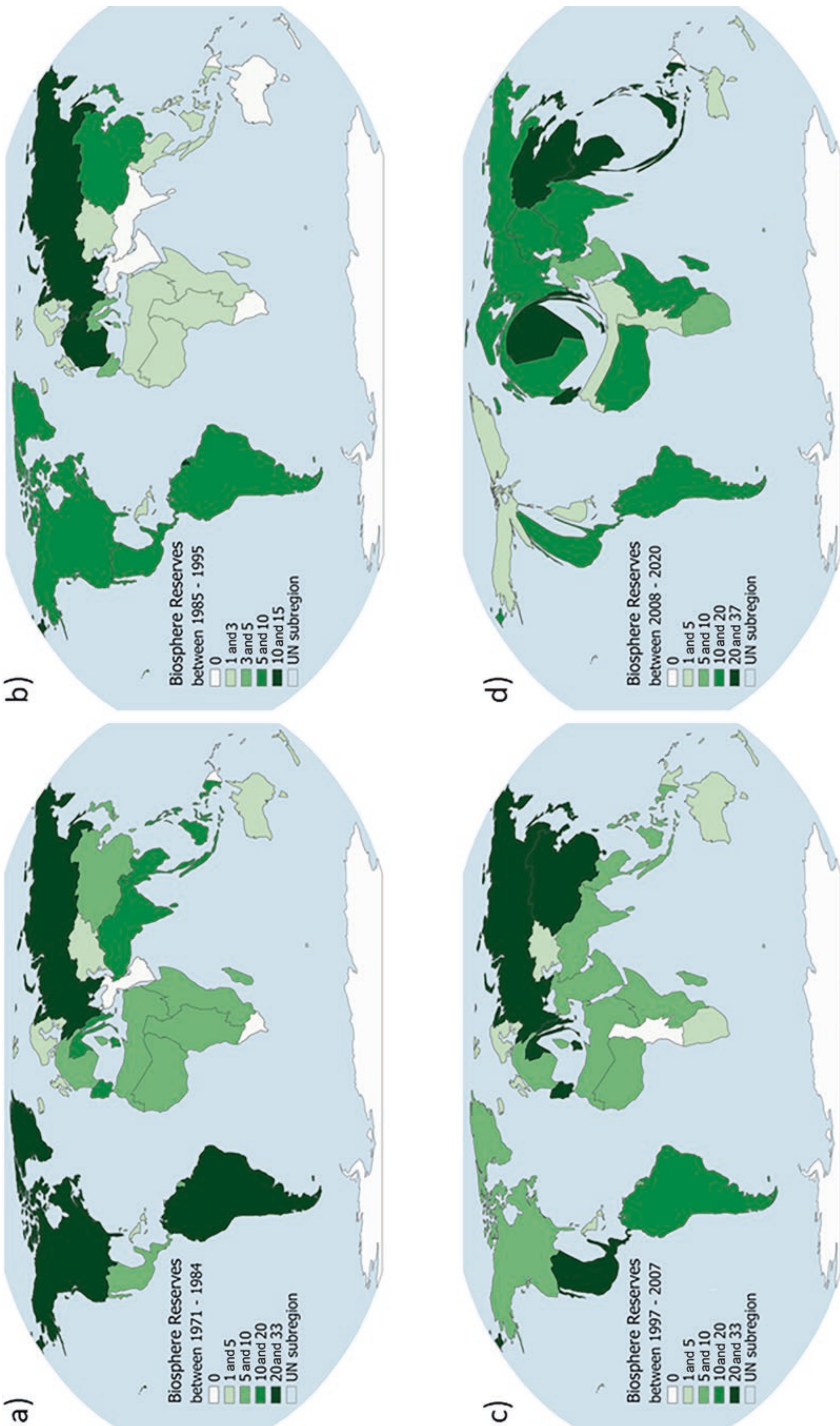


Fig. 13.5 Cartogram of the global distribution of UNESCO Biosphere Reserves within the UN subregions (**a**) between 1971 and 1984, (**b**) between 1985 and 1995, (**c**) between 1996 and 2007 and (**d**) between 2008 and 2020

during this period. In the first period, the number of biosphere reserves in Africa was comparably high. But since then, the number is barely growing (Ishwaran et al. 2008). The mentioned trend is continuing, as the cartograms in Fig. 13.5d show.

About 23% of biosphere reserves are located in Asia, which covers nearly 30% of the land area. Ishwaran et al. (2008) explained that especially in the post-Seville period, the number of reserves in Asia grew. The cartograms in Fig. 13.5a–c show that this trend is not uniform. The Southern Asian subregions grew more than Eastern Asia in the first phase and vice versa in the second phase. In the period from 1996 to 2007, all Asian subregions grew. The cartogram in Fig. 13.5d shows that this trend continues, as all subregions get larger.

13.4 Conclusion and Outlook

This study used the distribution of UNESCO World Heritage Sites, Biosphere Reserves and Global Geoparks to explain and illustrate potentials of cartograms for spatial and temporal GIS analysis. In this context, cartograms are a method to illustrate spatiotemporal biases with the help of statistical values.

Since the adoption of the UNESCO World Heritage Programme, the distribution of world heritage sites has become a major subject of concern. The imbalance of world heritage sites and the inefficiency of the Global Strategy was already described by Steiner and Frey (2011). The cartograms in this work confirm that the imbalance towards Southern and Western European subregions increased after the declaration of the Global Strategy in 1994 and added a spatial aspect to this imbalance. In the last 10 years, Eastern, Southern and Western Asia caught up with the designation of world heritage sites. However, since the Global Strategy in 1994, the dominance of world heritage sites in European subregions has been negligible.

Ishwaran et al. (2008) described the imbalance of biosphere reserves towards Europe. The cartograms show that Southern and Western Europe enlarged over all phases. The cartograms suggest that Eastern and South-Eastern Asia caught up in the designation of biosphere reserves during the last 12 years. However, the global imbalance in the distribution of biosphere reserves, especially towards Southern and Western Europe, could not be compensated, and hence, the pattern of biosphere reserves is still spatially imbalanced.

The cartograms created in this work are based on the designated numbers of sites per subregion and, hence, cannot replace a statistical analysis as conducted by Steiner and Frey (2011) or Ishwaran et al. (2008). Therefore, future work needs to focus on a comprehensive statistical analysis of the last 10–12 years for world heritage sites and biosphere reserves. These statistical values can then be processed to cartograms to illustrate spatial imbalances.

In general, reliable geodata and GIS tools can support and monitor global policies. Additional geodata like area information for biosphere reserves or global geoparks can refine analysis like the cartograms in this work. Therefore, geodata and open-source GIS offer value-added analysis beyond tables and diagrams.

13.5 Tutorial

The UNESCO World Heritage Programme is an important mechanism to protect and preserve cultural and natural heritage with outstanding value to humanity. Some sites are threatened by wars, climate change, natural disasters, lack of conservation policy or deterioration of the space or environment. Endangered sites can be placed on the List of World Heritage in Danger (Badman et al. 2009). This can alert the international community to the danger and preserve the affected sites with financial and practical help (Hølleland et al. 2019). There are currently 53 sites on the list (UNESCO 2021a). The website "World Heritage in Danger" of UNESCO provides additional information (https://whc.unesco.org/en/158/).

The aim of the provided exercises is to reproduce the workflow of the presented analysis with the dataset of UNESCOs "World Heritage in Danger". The task is suitable for beginners and intermediates. To overcome a cognitive overload by the complexity of the software, video tutorials are embedded in the website with the exercises. The exercises and data are available via the following GitHub project: https://github.com/GeowazM/The-Network-of-UNESCO-Sites_Changes-Patterns-visualized-with-Cartograms.

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Glossary

ArcGIS GIS software, belonging to ESRI, used for the creation, editing, analysis and display of spatial data.

Attribute table A table that stores the attributes of a specific type of elements within a vector dataset.

Base map A map that is used to provide a minimum level of support, or a general framework, upon which other geospatial information can be superimposed.

Cell size Dimensions, expressed in units of terrain, relating to a raster cell.

Control points Points used for georeferencing scanned maps.

CRS (or Coordinate Reference System/coordinate system): A reference system that makes it possible to define positions in a two (or more) dimensional space, through the use of pairs or, more generally, tuples of values which express distances or angles with respect to the axes or reference plane that define the system.

Data view [In ArcGIS] The data view provides a geographic window for exploring, displaying and querying the data on your map.

DEM (or Digital Elevation Model/Elevations) elevation layer.

Ellipsoid The surface of a three-dimensional body whose flat sections are always expressed as ellipses or circles.

Expression A sequence of operands and operators constructed according to the syntactic rules of a determined symbolic language which, once evaluated, gives rise to a single value, which may be numeric, textual, Boolean, etc.

GeoPackage An open, and non-proprietary, spatial data format built on the SQL-Lite database, and developed by the Open Geospatial Consortium.

Georeference To locate on a map of the earth or another cartographic document, or the representation of a geographic object via the value of its coordinates.

Layer The type of elements of a set of geospatial data that constitute the digital representation of a determined type of geographic entities.

Layout Composition of the map.

Merge The Merge vector layers function provides an algorithm that combines multiple vector layers of the same geometry type into a single layer.

National topographic map A topographic map, usually at the scale of 1,50.000 or 1,25.000, which serves as a base map for the territory of a nation, or state, and which is intended for use in multiple applications and by a wide range of users.

Old map A map created in the past and which now no longer serves the purpose that it was originally designed for.

Orthophoto Aerial photography in which the distortions caused by factors such as camera tilt, perspective and differences in the relief of the terrain have been corrected so as to maintain a constant scale and permit is used as a planimetrically correct map.

Projection The transformation of the positions and forms of the ellipsoid surface of the Earth on a plane in order to represent them as a map.

QGIS Free and open-source GIS software, used for the creation, editing, analysis and display of spatial data.

Rasterize To transform a cartographic document from vector to raster format.

Shapefile An open, geospatial format developed by ESRI Inc., which stores elements according to a simple vector data structure, without topology.

Symbolize To represent information on a map, or another cartographic document, using cartographic symbols.

Slope The inclination of the surface of a terrain, which can be measured in angular values (degrees), gradients or percentages.

UMZ (or Urban Morphological Zones) A set of urban areas that are less than 200 m apart.

Ungeoreferenced map A map which does not have coordinates that belong to a coordinate reference system that the software can understand.

Vector dataset A set of geospatial data consisting of elements represented as vectors.

Vectorial layer Referring to the structure or format of the cartographic information that is based on lists of coordinates that describe the location of the points, lines and polygons that constitute the geometry of a territory.

Vectorize Converting raster data into vector data.

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