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Environmental Issues at the Territorial Level

Etienne COSSART
EVS, UMR 5600, CNRS, Université Jean Moulin Lyon 3, France

1.1. Introduction

Studying environmental issues encompasses a triple objective: to monitor changes in the quality of the living environment (biophysical, ecological and social); to understand the extent to which human settlement contributes to these changes of state; and finally, to help formalize remediation strategies in a decision-support approach. The notion of change is central and is part of the paradigm of global change. The notion of global change emphasizes understanding the short- and long-term interactions between climate, the biosphere, the ocean, the solid Earth and, of course, human activities (Goudie 2017). Particularly formalized in the development of the Gaia Hypothesis (Lovelock and Margulis 1974; Lovelock 1993), this notion serves as the basis of a conceptual framework that invites us to consider the Earth as a whole, as a complex system that interacts with multiple parts. These parts are all spatial subsystems, the mechanisms of which geographers must study and ultimately formalize the modalities through which they manifest in the territories.

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Territorial Analysis of Environments,
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One of the difficulties encountered in this work is that a spatial system is driven by multiple interactions, which are not necessarily synchronous but linked over time. François Durand-Dastès (2001) emphasizes the importance of temporal factors in the geographer's explanatory arsenal (Figure 1.1), particularly the weight of legacies and the effects of "path dependence". Environmental changes are phenomena in which history matters: what happened in the past persists due to resistance to change. As a result, interactions, or mechanisms formalized, for example, in sagittal diagrams schematizing the operation of spatial systems, must consider the arrow of time (Figure 1.1). The methods for reconstructing continuous time will be presented in the following chapter. This chapter explains how reconstructing the evolutionary trajectories of the environment enable the necessary step back to identify and interpret the environmental changes that affect territories.

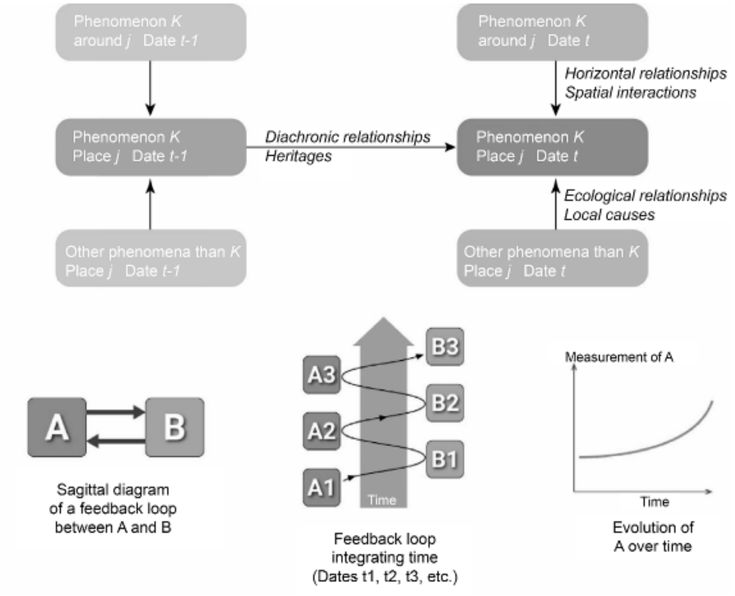

Figure 1.1. *Integration of time in geography. At the top: time and the resulting diachronic explanatory relationships are part of the three main explanatory relationships in geography. At the bottom: principle of integrating continuous time from a simple sagittal diagram (adapted from Durand-Dastès 2001)*

However, such identification is not easy: it implies aligning data concerning the evolution of the physical environment with territorial scales, characterized by their unique mesh. Spatialization work thus renders the geographical approach indispensable in the realm of research on environmental changes. This spatialization effort poses a dual scientific challenge. Firstly, it involves mapping the effects of changes at local, fine scales, recognizing that at this level of analysis, the consequences of environmental changes can vary remarkably due to local contexts (topography, exposure, etc.). However, many researchers in related disciplines (particularly Earth sciences) only address changes at large scales, whether through studies based on stationary measurements or general models. These results often smooth or obscure the effects of these local contexts. Therefore, are these results significant and tailored to the local specificities of the territories? What enrichment can downscaling bring to the analysis of changes at these large scales? In addition, the consequences of environmental changes must be mapped within territorial grids: it is at these levels of analysis that we can provide guidance to environmental managers and practitioners who operate within them. Of course, adaptation to these scalar levels requires spatial analysis work, striking a balance between respecting the spatial variability of observed phenomena and the necessary process of generalization.

These two challenges, tied to the descent of scale and the adaptation of diverse data (especially biophysical data) to territorial scales, underscore the value of a geographical and cartographic approach in studying environmental changes. These challenges are sequentially illustrated in this chapter.

1.2. Consideration of local context effects in environmental changes

The dynamics of environmental change, whether retro- or prospective, are analyzed and mapped on broad spatial scales that often fail to meet the needs of decision-makers, particularly regarding climate change adaptation. For instance, paleo-environmental data lose spatial resolution as we delve further back in time beyond a few decades, while climate projections for 2050 or even 2100 are conducted at macro-regional or continental scales. The outputs of general circulation models (GCMs) for the atmosphere typically cannot achieve a finer resolution than 100 km x 100 km.

Downscaling methods offer a solution to generate information at finer scales than the original projections. Rather than merely interpolating data into a finer grid resolution, these methods enhance model outputs by incorporating additional data that capture local characteristics. These data, which are often precluded from integration into global models due to computational limitations, enrich the analyses.

The development of downscaling methods is ongoing. While not providing an exhaustive overview, we present some simple techniques to grasp the enrichment they afford and their contributions to impact studies, planning or decision-making processes.

1.2.1. *Principles of downscaling*

Global climate projections remain indispensable tools for capturing the extent of ongoing and future changes. However, they often fall short in representing the heterogeneity of climate changes at a fine scale. Features such as topography, bodies of water and land use characteristics are not accounted for, despite their direct influence on what climatologists refer to as topoclimate (Beltrando 2010). Nonetheless, integrating this heterogeneity is crucial for anticipating the potential impacts of climate change at the territorial level. Agricultural productivity, hydrology and species distribution, for instance, are heavily influenced by local biophysical parameters (Figure 1.2).

There are two primary approaches to enhancing climate projection data by incorporating information on local conditions:

– Dynamic method: this entails explicitly integrating additional physical data and processes into models akin to GCMs, albeit at a finer resolution that covers only certain parts of the globe. However, this method requires calculations and data volumes that often exceed typical computing capacities.

– Statistical method: this involves calibrating statistical relationships between data generated at a broad scale and local characteristics. Facilitated and commonplace through GIS or data processing software, they can be executed with minimal IT knowledge and resources. Statistical relationships are calibrated based on already acquired climate observations, from which causal mechanisms could be identified. These methods rely on an assumption of stationarity, meaning that the observed statistical relationships currently will persist into the future. This caveat underscores that projections are not strictly predictions but simulations revealing trends aimed at supporting managers.

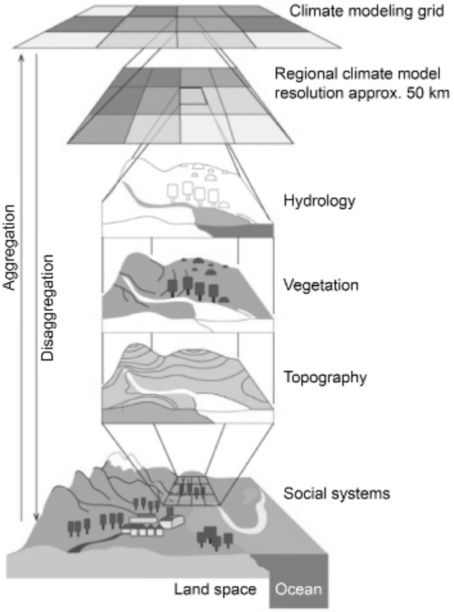

Figure 1.2. *Principle of downscaling and climate data enrichment at fine scales (according to Beltrando 2010)*

1.2.2. *Statistical method to detect local particularities*

The modalities of environmental change in general, and the impacts of climate change in particular, can vary spatially. This issue is exemplified, for instance, in mountain environments where the topoclimate exhibits significant variability due to altitude, exposure effects and slope morphology (Gottardi et al. 2008; Joly et al. 2009). In the environmental domain, as in the realm of climate, spatial heterogeneity in statistical relationships at fine scales is common. For instance, the density of canopy cover can significantly influence temperatures on slopes highly exposed to solar radiation (due to shading effects), whereas this moderating effect is less pronounced on slopes already less exposed to the sun.

To address these challenges, geographically weighted regression (GWR) can be employed to model a phenomenon in which both the causal variables and the modalities of their combination vary spatially. GWR generates different regression coefficients for each location within the study area. Data points closer to a given estimation location exert a stronger influence on the model compared to those farther away. Consequently, the parameters of the regression equation vary spatially, resulting in different estimates for each location (Box 1.1).

Mathematical formalization of the GWR modeling temperature

For each given meteorological station (located at longitude X, latitude Y) in a study area, it is possible to fit a regression that estimates local temperature values T(X,Y) using the predictors Vi(x,y) measured in the vicinity. A greater weight is assigned to a station (x,y) close to the station point (X,Y) through Gaussian kernel smoothing. The formula would be as follows:

$$T_{X,Y}(x,y) = \beta_{0\ X,Y} + \beta_{1\ X,Y} * V_1(x,y) + ... + \beta_{n\ X,Y} * Vn(x,y)$$

where X,Y are the coordinates of a location where the temperature prediction (T) is made. (x,y) are the coordinates of all surrounding measuring stations, β_0 β_1 β_n are the spatially varying coefficients (β_0 represents the intercept, β1 and βn are the regression coefficients of the predictors) and V_1 to V_n are the explanatory variables (i.e. predictors). This equation can be adjusted by least squares to provide parameter estimates at the location (X,Y) and calculate a modeled temperature value there.

Box 1.1. *Principles of Geographically Weighted Regression (GWR)*

GIS software facilitates the implementation of these geographically weighted methods. In the environmental domain, the most common scenario involves a dependent variable that we aim to explain or estimate at any point within the study area based on point data (such as temperature data acquired from stations). Predictive variables are continuous variables, represented in raster format within regular grids. GWR is applied to a regular grid and determines regression coefficients, which can be interpreted as partial derivatives of temperature with respect to each predictive variable. Some model outputs provided by software enable the mapping of these regression coefficients, revealing their spatial distribution (Cossart 2013; Feuillet et al. 2014). This allows for the measurement of the variable's sensitivity to each predictor at every point in the study area. A higher partial coefficient of a predictor at a point indicates a greater influence on temperature, as even minor local variations in the predictor can lead to significant temperature changes.

1.2.3. *Enriching regional or even global models at the local level*

Many model outputs aim to illustrate, very pedagogically, the potential impacts of ongoing climate change by 2100. While essential for raising awareness of these issues, these models are often established at very broad scales, which is sometimes seen as a hindrance to their effective uptake by local stakeholders (Beltrando 2010). Vegetation maps produced at the scale of France provide a telling example (Figure 1.3). They depict the potential northward and eastward shift of current large plant formations, as well as the shrinking range of beech forests. At this scale and level of resolution, some analysts express concerns about the ability of plant species to keep pace with this migration rate. However, at this scale, the effects of local contexts are smoothed out or even entirely obscured.

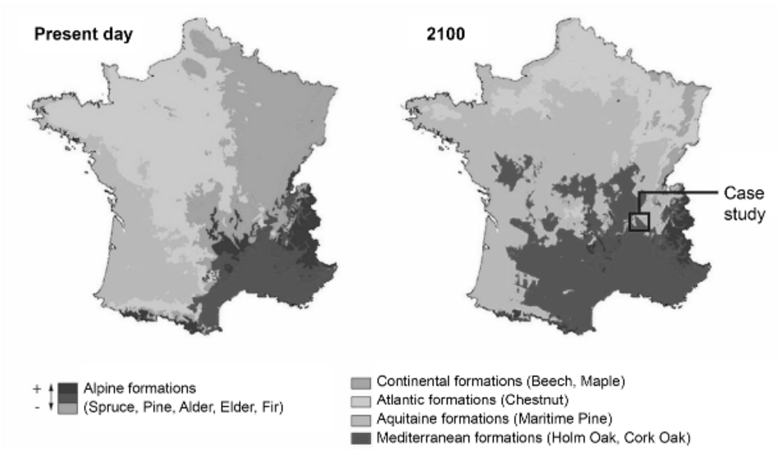

Figure 1.3. *Example of projection of the impacts of climate change on vegetation by 2100 (extracted from Ollat and Kremer 2013)*

Through downscaling, it is possible to locally enrich these model outputs to identify potential refuge areas, linked to the topoclimate and not detectable at a large scale. By focusing on the region from Lyon to the Prealps, GWR allows us to model the distribution of current temperatures based on a few point data and by integrating simple topoclimatic variables: altitude, incident solar radiation and topographic concavity (cold air tending to be trapped in concave areas by gravity).

The results (see Figure 1.4) show that by integrating local conditions on a 40 x 50 km grid, temperatures can vary from 8.8 to 15.2°C around the mean (estimated here at 11.75°C). Without aiming to replace climate modelers, the integration of this local temperature variability can be leveraged as part of a territorialized support approach. Indeed, assuming that the scenario established by 2100 is based on a 2°C temperature increase, areas currently experiencing temperatures 2°C below the grid average are likely to become refuge zones for the plant species currently present there.

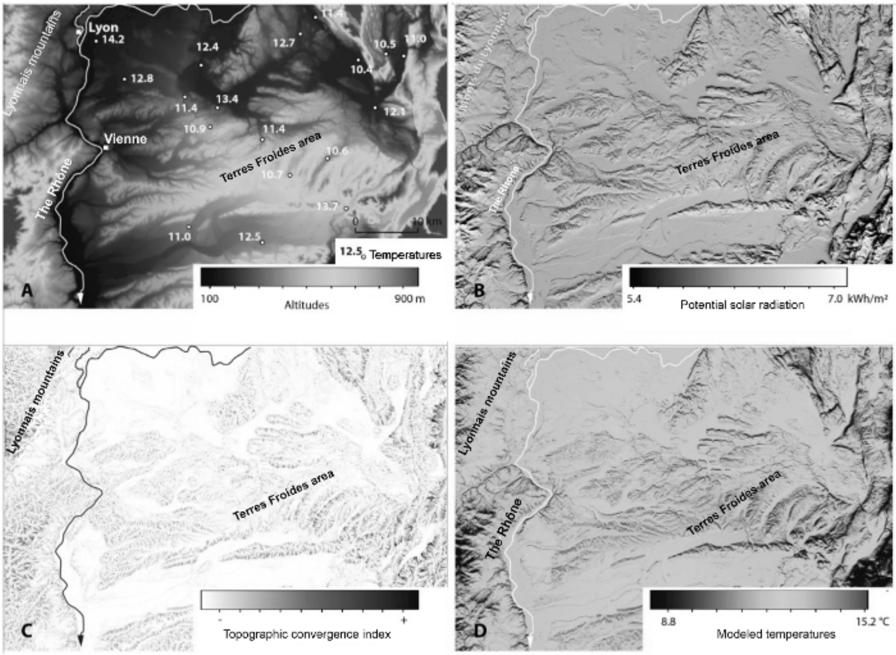

Figure 1.4. *Temperature field modeling by GWR integrating local data. A: altitude and climate data (ROMMA stations, May 2022); B: incident solar radiation; C: topographic concavities; D: GWR results. Processing performed in SAGA GIS*

The identification of refuge areas (Figure 1.5) must be interpreted cautiously, and the results should not be regarded as predictions. These are hypotheses, yet they serve to highlight priorities in terms of adaptation strategies. They illustrate the fragmentation and reduction of areas where current vegetation could persist, underscoring the potential impacts. Moreover, these refuge areas are concentrated in specific regions: the Lyonnais mountains and the Terres Froides area (especially on north-facing slopes). If the goal is to prevent plant species from experiencing range migration on a macro-regional scale, then these potential refuge areas need to be used. This includes, for instance, facilitating the movement of threatened tree species, such as beech, to these areas through management strategies. In addition, these scarce refuge areas must be preserved, specifically by being shielded from land pressure and urban expansion.

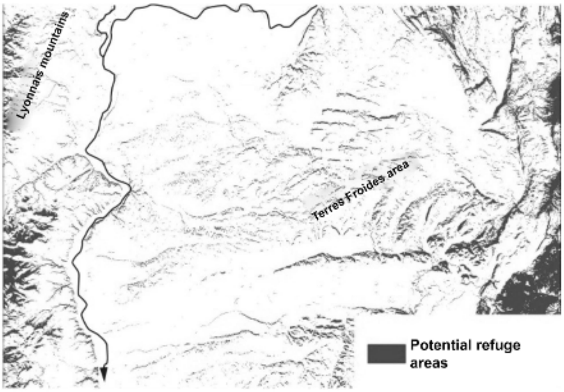

Figure 1.5. *Identification of potential refuge areas for vegetation by 2100 (+2°C scenario)*

1.3. Environmental changes in territorial units

The territorial units are where action takes place, whether in environmental management or more broadly in development. At the finest level, the cadastral parcel, actions result from the choices made by the owner combined with those of the user (who may be different from the owner). From this combination emerge, for example, land use patterns and their changes over time. At broader levels, from the municipality to the state, each level is characterized by actors with their own prerogatives. At the municipal level, land use patterns are regulated by the French Local Urban

Development Plans (law of December 13, 2000, on urban solidarity and renewal, Articles L. 123-1 and following). At the departmental level, an inventory of sensitive natural areas or agricultural and peri-urban natural areas is conducted for their management. The units, cartographic objects representing the territories, must therefore contain environmental information useful to managers who take action, informing their decisions and potentially enabling planning. Although GIS software aids in data management across different observation levels, this work requires upstream conceptual formalization – building objects that must make sense, both to reflect the spatial variability of biophysical phenomena and for actors operating at specific levels. In this formalization work, the operator must deal with the Modifiable Area Unit Problem, sometimes a highly distorting mirror of territorialized data.

1.3.1. *MAUP: Modifiable Area Unit Problem*

Defined by Openshaw and Taylor in 1979, the MAUP refers to the influence of the geometry of the territorial grid on the results of statistical and, of course, cartographic processing. In detail, the MAUP is related to the combination of a scale effect and a zoning effect.

The scale effect directly affects density calculations, whose value depends on the chosen surface area and the size of the units. Units with a large spatial extent tend to aggregate different types of local contexts, ultimately returning a value derived from the average observed across these multiple contexts. The resulting values tend to be smoothed. Conversely, smaller units can align with very specific local contexts, whose values are not averaged by other internal contexts. Consequently, the unit may return an extreme, unsmoothed value.

The zoning effect presents a boundary problem. Figure 1.6 illustrates that, from the same initial data and at the same scale, different partitioning geometries will affect the mapping results. Data acquired at the individual level correspond to an inventory of hardwoods and conifers. By dividing the territory into areas of equal size but with three different geometries, three different representations can be obtained: equal distribution, dominant coniferous or dominant deciduous.

The chosen grid for an analysis can indeed distort a result. This distortion is primarily cartographic, biasing the representation and the interpretation of the distribution patterns of a phenomenon. In addition, it is analytical because the level of an indicator depends on the observation scale and the geometry of the units associated with that scale.

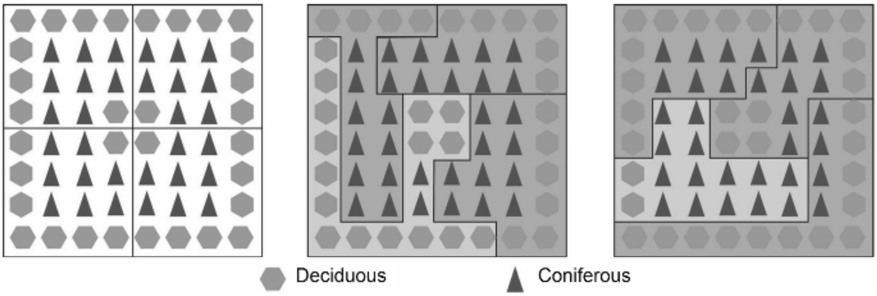

Figure 1.6. *Illustration of the zoning effect of the Modifiable Area Unit Problem (MAUP)*

There is no universal method for dealing with MAUP. Furthermore, in the field of environmental geography, analysts face the challenge of correlating biophysical phenomena, often continuous or at least unconstrained by administrative boundaries, with territorial grids. Thus, careful consideration of treatment methods is crucial when connecting diverse phenomena (e.g. biophysical, social, economic) with sets of actors involved at a particular scale.

1.3.2. *Integrating environmental data into territorial grids*

We illustrate the MAUP with the environmental challenge posed by the conifer planting in the Morvan, a mid-mountain massif in the western part of the Bourgogne-Franche-Comté region. This approach leads us to compare data concerning land use patterns in general (and forest cover in particular) with territorial units. There are numerous freely available databases, such as the IGN’s BD Forêt databases (used here) or Corine Land Cover (refer to Chapter 8). They result in a partitioning of the territory, the geometry of which directly impacts cartographic representations and subsequent interpretations.

1.3.2.1. *Choosing the scale*

The scale is often chosen implicitly, without anticipating the consequent implications and biases. The choice is to be made according to the question asked and in particular, in the case of environmental data, the type of causality sought and the type of actors involved in the analysis (Dollfus 1993). Applied to the challenges of the conifer planting in the Morvan (Figure 1.7), the municipal level, for example, can be relevant for comparing data on the state of forest cover with two potentially explanatory variables related to the agricultural trajectory (expansion vs. decline of agriculture) and the demographic trajectory (rate of depopulation).

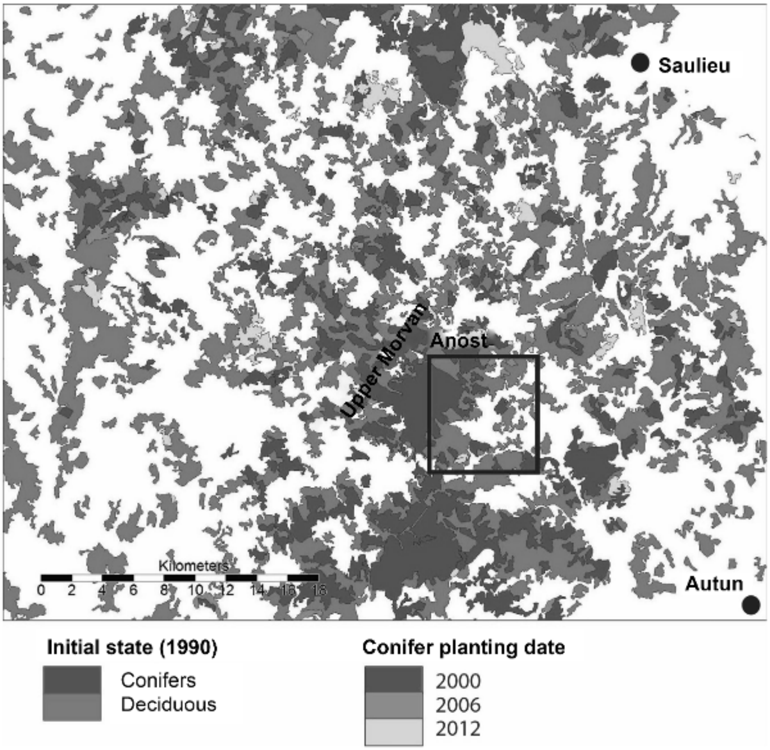

Figure 1.7. *Example of fragmentation during the construction of a diachronic map without a stable grid over time (Corine Land Cover data)*

In the present case, we have chosen to work on a finer scale, on the parcel scale within a municipality affected by conifer planting since the mid-20th century: Anost (Upper Morvan, Saône-et-Loire). Creating a map of conifer planting at this level may seem surprising, but it serves three objectives.

Firstly, the very fine cadastral parcel grid is often a stable geographical object over time, facilitating diachronic comparisons and the mapping of evolutionary trajectories. Indeed, diachronic maps directly derived from zoning that varies over time, such as those produced by online databases, are often illegible. Geoprocessing procedures in GIS software generate multiple divisions, resulting in fragmentation that impedes visualization and, from a data management perspective, artificially creates new entities that may lack coherence (Figure 1.7). Secondly, at the parcel scale, land use patterns (and transitions between these patterns) are linked to choices made by owners and/or users. This allows for illustrating the typology of choices made by these stakeholders and potentially comparing them with location characteristics (accessibility, topoclimatic context of the parcels) or land attributes (parcel size). Finally, it is important to note that legal documents such as the Local Urban Planning Plans reflect a comprehensive development and urban planning project and consequently establish regulations for land development and use at the level of municipalities or municipal groups. They regulate the use of parcels and require an assessment and diagnosis at their scale.

1.3.2.2. *Illustration of the MAUP*

A map depicting land use patterns at the parcel level in the municipality of Anost is created through expert photo-interpretation for the years of 1960 and 2018 to capture their evolution. Each parcel is assigned the dominant land use observed in aerial photographs. Since entities (parcels) maintain a consistent geometry over time, this map is complemented by an alluvial graph representing the types and frequencies of observed transitions (Figure 1.8).

The outcome reveals a distinct reduction in agricultural areas, which have decreased by one-third between 1960 and the present. Parcels undergo conversions into deciduous forest, coniferous forest and mixed forest in a relatively balanced manner. Notably, smaller parcels near urbanized areas are more frequently converted into mixed forest. Another notable trend is the emergence of conifer planting: negligible in 1960, it now covers over 20% of the municipal territory. This conifer planting is primarily driven by the conversion of deciduous forest parcels, with a lesser contribution from the conversion of agricultural plots. Mapping at the parcel level highlights a clear land use logic that would otherwise remain undetectable. Specifically, the conversions from deciduous to coniferous forests predominantly occur in large parcels, underscoring the significant role played by large landowners and investors at the onset of this dynamic.

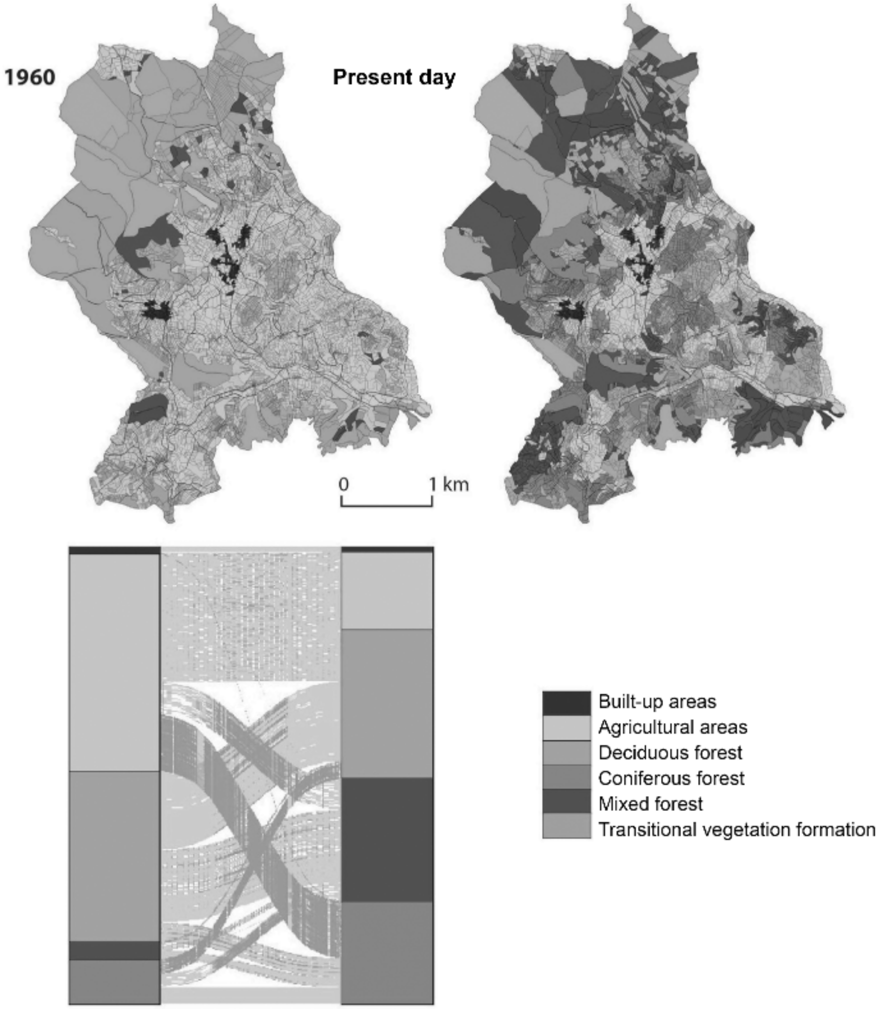

Figure 1.8. *Evolution of land use patterns in Anost (Upper Morvan, Saône-et-Loire) from 1960 to the present day (Source: IGN photo-interpretation data)*

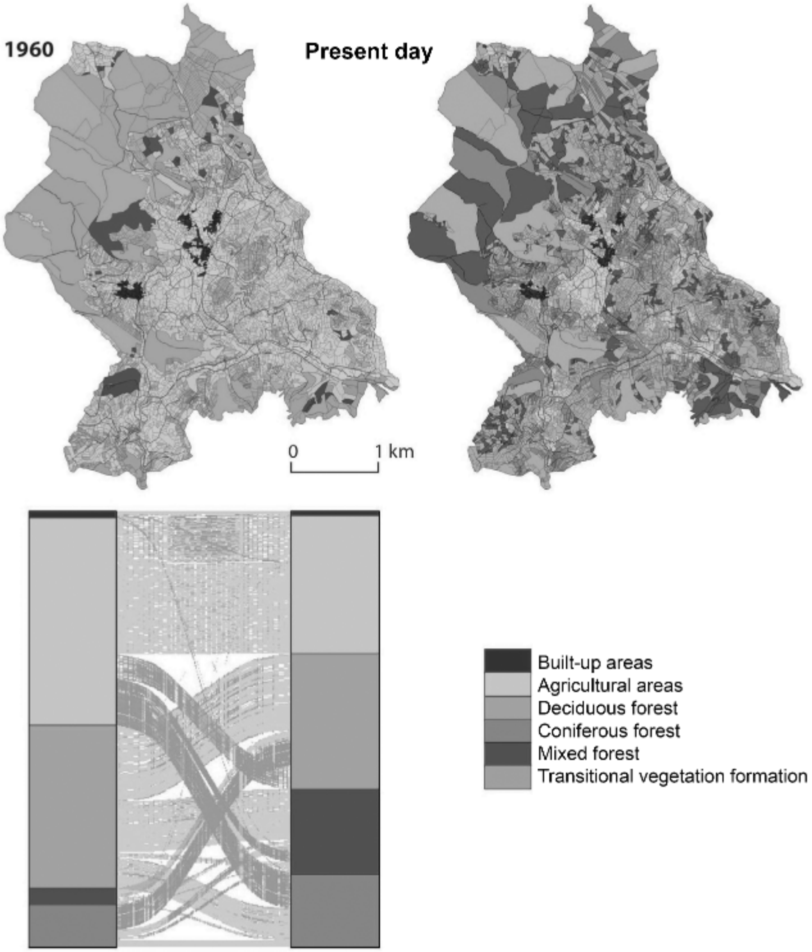

Figure 1.9. *Evolution of land use patterns in Anost (Upper Morvan, Saône-et-Loire) from 1960 to the present day, integrating the Forêt database and the Registre Parcellaire Graphique (Source: IGN)*

Simultaneously, for the year 2018, another land use map was generated using the freely available data from the Graphical Parcel Register (for agricultural land use patterns) and the Forêt Database (detailed databases in Chapter 8). Both databases are produced by IGN. Regarding data processing, the polygons representing different land cover types are intersected by the polygons corresponding to the parcel grid, following a protocol previously formalized elsewhere (Cossart 2024) and implemented in SAGA GIS.

While not contradictory, the trends observed from these “online” databases tend to exaggerate the extent of agricultural area contraction and the increase in forested areas (Figure 1.9). Within the forest, the proportion of softwoods is notably lower compared to the mapping obtained through photo-interpretation. Nevertheless, this method confirms that the emergence of softwoods predominates in large parcels of land.

Integration of environmental data into territorial grids reveals distortions related to the MAUP. In this case, field verification shows that these distortions are more pronounced when mapping is based on free, previously generalized and simplified data. Territorial mapping, however, provides opportunities to monitor environmental changes and develop explanatory hypotheses for the processes driving these changes. Such processes can only be identified at specific levels, where specific actors are involved. This underscores the value of this mapping: understanding the decisions made by actors and revealing trends that can assist these actors in decision-making. However, due to the risk of MAUP-related distortion, these maps should not be used for raw quantification of environmental changes.

1.4. Conclusion

Even though some environmental geographers produce unpublished data on changes affecting the biophysical environment, and in particular climate change, a more transversal legitimacy to the community lies in the development of model outputs at operational scales, aligned with territories. Transposing any scientific result for use in development is a job in itself. First, it is a question of descending into the analysis scales, by enriching the outputs of models developed at the global or macro-regional scale to take into account the local specificities of the environment. A rereading of the issues of adaptation to ongoing changes is then possible, such as the identification of refuge areas to be preserved to ensure the maintenance of threatened plant species. It is also a question of proposing the mapping of indicators of current changes at levels adapted to scientific questioning, and also in the formulation of adaptations specific to each territory. This work requires mapping in territorial grids that have a scientific sense (level at which we can formalize spatial associations, statistical correlations) and a sense for decision-makers (level at which they operate). Even though these cartographic translations suffer from MAUP, hindering the rigorous quantification of developments, they constitute an element of reflection in the formulation of adaptation factors.

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