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Dynamics of rural landscapes and their main driving factors: 
A case study in the Seine Valley, Normandy, France

Isabelle Poudevigne a, Sabine van Rooij b, Pierre Morin a, Didier Alard a, *

a Laboratoire d'Ecologie, UFR Sciences, Université de Rouen, F-76821 Mont Saint Aignan Cedex, France
b Department of Environmental Studies, University of Nijmegen, Postbus 9010, 6500 GL Nijmegen, The Netherlands

Received 2 October 1996; accepted 17 April 1997

Abstract

Land cover and landscape patterns dynamics over a 25 year period are analysed for a case study in Normandy. With the help of cartography, GIS and multivariate analysis, factors contributing to landscape structures and changes are studied. The results point out three main driving factors responsible for the landscape change: Agricultural practices which lead to intensification of some areas and abandonment of others, urbanisation which modifies the structure and organisation of the landscape, and finally, as factor of stability comes the conservation policies which check these changes in certain zones. Despite this last factor, the global resulting impacts are, up to now, the progressive disappearance of the organisation of the sites landscape. © 1997 Elsevier Science B.V.

Keywords: Rural landscape; Landscape dynamics; Landscape organisation; Cartography; Multivariate analysis; Urbanisation; Agriculture; Nature conservation; Seine Valley; Normandy

1. Introduction

Analysing landscape patterns and dynamics is one of the main goals of landscape studies, whether on an ecological basis or a geographical one. The first scientific aspect deals with modelisation of ecological functioning and processes at the landscape scale. (Turner et al., 1990). Landscape changes are also an important part of environmental earth dynamics, also called global changes (Vitousek, 1994). The second scientific aspect is mostly involved in studying how rural human societies model their landscape and their environment (Spedding, 1984).

All these studies using very different tools have pointed out different causes and effects of landscape dynamics. The main driving factors have been identified as agriculture intensification (Green, 1990; Harms et al., 1984) or urbanisation (Phipps et al., 1986) in the context of local or national policies (Kubes, 1994; Lipsky, 1992; Meeus, 1993).

The present paper deals with rural landscape dynamics in the Normandy region and specifically in the Seine valley. The landscape of this valley is historically modelled by agriculture and offers a very specific landscape pattern (natural mosaic of wetlands, ploughed areas and chalk grassland across a topographical gradient). Today this area and the site of St Martin de Boscerville in particular, is subject to the intensification of agriculture which holds a large part in explaining the landscape dynamics.
Many outside pressures also contribute such as the growing urbanisation of the nearby town of Rouen or the protection measures of the Regional park it is part of. As a changing rural site, subject to such pressures, St Martin offers an complete case study for the assessment of rural dynamics and it's driving factors (Alard and Frileux, 1992).

We have tried to monitor landscape dynamics in this area in order to assess and to localise the changes. In a second stage we have tried to assess the main driving factors of these dynamics: On one hand the presumed driving factors of change (agriculture and urbanisation) and, on the other, a presumed factor of stability (the various site protection and nature conservation systems effective on the site).

1.1. Study area

The site chosen for this study lies on the banks of the Seine, west of Rouen. The area comprises 4100 ha and corresponds to 4 municipalities: St Martin de Boscherville, Quevillon, Henouville and St Pierre de Manneville, thus its boundaries are administrative limits (Fig. 1). The interest of this site lies in the fact that it is a microcosm of most of the habitats present in Normandy.

2. Methods

Data used to describe the St Martin landscape and the driving factors behind the dynamics observed, are detailed in Table 1. To analyse these different data and to make calculations for comparing them, use was made of the Geographical Information System Macmap 1.3 (Klik Développement, France). The maps and the aerial photographs were scanned and lead directly into the Macmap program. Each object of those maps (point, line or surface) pointed out by Macmap was identified. As concern the aerial photographs, eight major landcovers were distinguished. A series of thematic cartographies (or files) of the site were thus obtained: soil types, landcover in 1964, landcover in 1989, plot limits and linear structures. To visualise the organisation and changes of the St Martin landscape between 1964 and 1989, a representative transect (i.e., where most of the different habitats present are represented) of these above

Fig. 1. The study site of St Martin de Boscherville: General situation in Normandy and grid presentation. The transect studied is localised on four grids at the level of Quevillon.
Table 1
Nature and source of data

<table>
<thead>
<tr>
<th>Nature of data</th>
<th>Source</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural features</td>
<td>Topographical map scale 1:25000 (IGN)</td>
<td>1982</td>
</tr>
<tr>
<td></td>
<td>Geological map scale 1:50000 (BRGM)</td>
<td>1964</td>
</tr>
<tr>
<td>Landcover features</td>
<td>Aerial photographs (IGN), scale 1:20000</td>
<td>1964 and 1989</td>
</tr>
<tr>
<td>Agricultural structures</td>
<td>In situ survey of 10 farms on 330 ha situated in Henouville and St Martin, comprised in 36 cells of the grid.</td>
<td>1994</td>
</tr>
<tr>
<td>Urbanisation</td>
<td>Value of the Habitation variable expressed by the analysis of the aerial photographs (IGN)</td>
<td>1964 and 1989</td>
</tr>
<tr>
<td>Protection devices</td>
<td>Map of the ZNIEFF inventory (CDM–DRAE)</td>
<td>1994</td>
</tr>
<tr>
<td></td>
<td>Map of the POS inventory from (DRAE)</td>
<td>1994</td>
</tr>
</tbody>
</table>

mentioned maps was selected. Their visual comparison already provides an interesting global approach.

These files were then used to calculate the organisation of the landscape in different years and to assess spatial correlations between the driving factors and the dynamics observed. The organisation index chosen for that purpose was index C defined by De Pablo et al. (1988) which is an index of the information theory group. Based on the amount of the relative abundance of land cover types in the different soil types, this index indicates the degree of mutual connectance between these sets. It is given by the formula

\[ C = \frac{H(V) - H(VS_j)}{H(V)} \]

where \( H(V) = -\sum p_i \log_2 p_i \) and \( p_i \) is the proportion of the landcover \( i \) variable, \( H(V) \) is thus the diversity (Shannon index) on the area, and where \( H(VS_j) \) is the diversity (Shannon index) on each soil type \( S_j \).

Some of the changes monitored are not at plot scale and some data are on different frame such as spatial diversity (inter plot measures). Thus, in order to take such data in consideration or to assess transformations linked to the structure of the landscape, the griding method was chosen. The site was thus divided in 134 cells of 600 m by 600 m for which the value of variables concerning either the landcover, the soils, the structural characteristics, or the agriculture were recorded (Table 2). Structural measures conditioned the size of the cells: They could not be realised on smaller squares since the cells would have had a uniform landcover, and could not have been realised on larger squares since the cells would have had too similar landcover proportions.

Treatment of these matrix (134 cells X groups of variables) by multivariate methods provided thematic grided cartographies of the site. PCA (principal components analysis) and HAC (hierarchical ascending classification) were realised with STATITCF software.

3. Results

3.1. The ‘natural’ organisation of the landscape: An agricultural heritage

The St Martin site at simple observation offers even today a very organised picture. This structured landscape is the heritage of many years of an agriculture bent to the natural characteristics of the land. So
as to visualise this organisation in 1963, the chosen transect of the site is represented according to both soil characteristics and landcover features (Fig. 2).

Their appraisal points out that landcover and soil types follow a topographical gradient. The upper part of the valley, with a clayey soil is covered with oak forest. The steep slopes of the valley, on calcareous soil, are mainly grazed grasslands. The lower slopes of the valley, which are very fertile because of the colluvial loess soil, are mainly managed in crop. The highest part of the flood plain is the habitation zone where the main road passes. The rest of the flood plain is mainly wet pastures or meadows where the small plots are surrounded by linear elements such as hedges, ditches and wooded banks, resulting in a so-called bocage landscape.

The griding and ordination of the landscape features (Table 2) permit to map the results expressed by the transect study (Fig. 3). The ordination and classification of the site’s landcover in 1963 produces a map of landscape types in 1963. The analysis by PCA of the matrix crossing the 9 landcover and ecological pattern features (Table 2) by 134 cells (or individuals) in 1963 brings up two main axis (added rate of representation of 57.6%). The first axis (40.5% of contribution to total variation) differentiates: High forest land from diversified low valley land. The second axis reveals the pasture in its matrix of hedges, two very closely correlated features.

The classification of the 134 cells by HCA proposes five types of structures in 1963: First a relatively diversified and rich landscape, where orchard, habitation and crop are clearly represented and though forest is absent, pasture holds an important share; the second is an even more varied landscape where each of the five main landscape elements are present usually in a matrix of crop; the third is a very moderately diversified view where crop and pasture are represented but are dominated by forest; the fourth is a landscape totally dominated by forest; the fifth is an equally poorly diversified landscape occu-
32. Changes in landcover and landscape organisation between 1963 and 1989

It is possible to measure this relation by calculating the $C$ index which reveals the organisation level of the landscape. The relative abundance (expressed as a percentage) of the types of landuse per soil type is determined by GIS in 1963. Index $C$ was calculated in a spectral form by varying the parameters, it has declined from 0.509 in 1963 to 0.360 in 1989, a decline of 29% in the total area. This suggests that habitat patterns and landscape structures have become less linked during this period.

The apparent disorganisation of the landscape can be visualised on the transect (Fig. 5). Essentially, the cultivation of the land in the flood plain and on the lower slopes has appeared together with the removal of the linear elements typical of the bocage and the enlargement of the plots. On the other hand, patches of early stages of land abandonment are observed on the chalk grasslands and some of the wetlands. New habitation areas have been created, notably on former chalk grasslands.

The grid analysis of the St Martin landscape in 1989 permits to localise and define the main centres of these changes. The typology of the 1989 landcover is realised in correspondence to that of 1963. Each cell in 1989 is replaced in the 1963 typology by comparing its values for the 15 variables with the mean values and standard deviation of each variable for each type. This gives us a type distribution of 1989 landcover and reveals major changes. Forest dominated landscape (types 3 and 4) have little changed, the bocage (type 5) has changed as pastures have left place to crops, this type thus clearly gaining in apparent structural diversity. Diversified landscapes (types 1 and 2) have evolved inasmuch to create a new type of landscape (type 6) which did

![Grid mapping of the natural habitat pattern provided by the ordination of the matrix (6 natural features × 134 cells) defined in Table 2.](image)
Fig. 4. Spatial distribution of landscape types as defined by the ordination for the site of St Martin in 1963 of the matrix (134 cells X 9 landscape features).

not exist in 1963, this less diversified landscape being dominantly composed of crops. Whereas in 1963 the presence of cropland in a cell was a guarantee for diversity, in 1989, cropland has developed unevenly creating instead a new uniform landscape. One must also notice that in all the types of land-cover where hedges were present in 1963, this linear structure has remarkably decreased in 1989 (by as much as 44% for some land covers).

The visualisation of the 1989 cells on the former 1963 typologies (the 1989 matrix being added as supplementary elements) clearly shows which cells have changed and how. Fig. 6 recapitulates the main changes which have occurred on the St Martin site. These changes can be grouped (by frequency analysis) into five main groups, changes in structural richness and diversity gradients being the main criteria of classification.

3.3. Presumed driving factors

The changes in agriculture observed in this region which are the passage from a pasture oriented agriculture to a more intensive crop oriented agriculture

Fig. 5. Transect of the St Martin site at the level of Quevillon, 100 m wide and 2000 m long.
no evident change of landcover at the cell scale

- gain in structural diversity (D) or richness (R) by gain of crops on a uniform grassland
- gain in structural diversity (D) or richness (R) by less Forest more crops
- loss in structural diversity (D) or richness (R) by more Crops in an already crop dominant landscape
- loss in diversity (D) or richness (R) by more grassland in an already dominant landscape
- no change in diversity or richness but change in landcover

Fig. 6. Map of the changes in landcover between 1963 and 1989 resulting from the frequency analysis of Table 4.

...have played their part in the landscape changes. Analysis by ordination methods of the data provided by the agricultural survey (Table 1) distinguishes two main farm types distributed among the 50 cells determined by the survey zone. The first groups 10 farms on 330 ha and is chiefly turned towards mixed...
cattle breeding milk/meat with a strong milk production dominance. The second represents 7 farms on 328 ha and follows the same activity but with a strong meat production dominance and some crops.

The localisation of these agricultural groups on the 50 cells, splits these cells into four types presented in Fig. 7. With the hypothesis that agricultural systems have little changed between 1989 and 1994, the crossed study of this agricultural typology with types of landscapes in 1989 reveals four main links: Farmers outside the studied zone are closely related to the 'meat dominant' farmers, 'meat dominant' farmers are largely linked to the rich flood plain (class 2) and to the poor croplands (class 1C), 'milk dominant' farmers are strongly linked to poor structures namely the poor flood plain pasture lands (class 1P), the diversified heights are occupied predominately by type D cells (both farming types are present). Table 3 illustrates the main differences between these two farming systems. To increase profitability, both have intensified their cultural practices. The first group (milk orientation) has increased its plot size (changes in landscape structure). The second group (meat orientation) has upturned pastures to cultivate crop (changes in landcover).

The studies of changes between 1963 and 1989 have shown that habitation has consequently changed as a rise of 13% in total landcover can be observed between 1963 and 1989. The study of the matrix crossing land types (Fig. 4) with habitation concentration types clearly reveals that in 1963 habitation was more linked with natural conditions than in 1989 (Table 4). In 1963 habitation is strongly linked to group B cells: The ancient alluvium just above the flood plain situated thus on gritty soils of no great agricultural interest but flat, easily accessible (highest levels of road vicinity), and above water level. Links with A cells show that some farms were situated close to the river on the alluvial ridge (i.e., above water level). In 1989 habitation is more linked to road vicinity than to the natural conditions of the landscape: habitation has expanded on group B and C lands where roads are most accessible and a little on group D cells (plateau land) along the roads. As a rule, urbanisation has increased where the agricultural pressure has decreased (e.g., chalkland slopes).

Table 3
Structural data on the two dominant farm types

<table>
<thead>
<tr>
<th></th>
<th>Total AA (ha)</th>
<th>GRA/AA</th>
<th>Mean plot size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk orientation</td>
<td>376</td>
<td>88%</td>
<td>2.52 ha</td>
</tr>
<tr>
<td><strong>Second group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meat orientation</td>
<td>252</td>
<td>72%</td>
<td>1.77 ha</td>
</tr>
<tr>
<td>Evolution</td>
<td></td>
<td>19% loss</td>
<td>1.52 ha in 1963 to 1.78 ha in 1989 (a 17.1% rise)</td>
</tr>
<tr>
<td>of the site</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AA = Agricultural area in use, GRA = Areas in permanent grassland.

Table 4
Table crossing land types (A, B, C, D) with habitation concentrations in 1963 and 1989

<table>
<thead>
<tr>
<th></th>
<th>$H = 0$</th>
<th>$0 &lt; H &lt; 20$</th>
<th>$20 &lt; H &lt; 40$</th>
<th>$40 &lt; H &lt; 60$</th>
<th>Total habitation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1963</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A: Modern all.</td>
<td>13</td>
<td>22</td>
<td>7</td>
<td>2</td>
<td>44</td>
</tr>
<tr>
<td>B: Ancient all.</td>
<td>10</td>
<td>9</td>
<td>2</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>C: Chalk slope</td>
<td>31</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>41</td>
</tr>
<tr>
<td>D: Plateau</td>
<td>17</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>Total land types</td>
<td>71</td>
<td>46</td>
<td>13</td>
<td>4</td>
<td>134</td>
</tr>
<tr>
<td><strong>1989</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A: Modern all.</td>
<td>15</td>
<td>16</td>
<td>9</td>
<td>2</td>
<td>44</td>
</tr>
<tr>
<td>B: Ancient all.</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>C: Chalk slope</td>
<td>31</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>41</td>
</tr>
<tr>
<td>D: Plateau</td>
<td>17</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>27</td>
</tr>
<tr>
<td>Total land types</td>
<td>73</td>
<td>37</td>
<td>18</td>
<td>6</td>
<td>134</td>
</tr>
</tbody>
</table>
Table 5  
Index $C$ for the landscape in 1963 and 1989, for zones under ZNIEFF inventory and zones under POS (Municipal land use planning)

<table>
<thead>
<tr>
<th></th>
<th>1963</th>
<th>1989</th>
<th>Change of $C$ in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total landscape</td>
<td>0.509</td>
<td>0.360</td>
<td>-29.3%</td>
</tr>
<tr>
<td>Area within ZNIEFF</td>
<td>0.696</td>
<td>0.580</td>
<td>-16.7%</td>
</tr>
<tr>
<td>coverage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area outside ZNIEFF</td>
<td>0.505</td>
<td>0.401</td>
<td>-20.6%</td>
</tr>
<tr>
<td>coverage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area within protected</td>
<td>0.536</td>
<td>0.484</td>
<td>-9.7%</td>
</tr>
<tr>
<td>zones of zoning plan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area outside protected</td>
<td>0.440</td>
<td>0.332</td>
<td>-24.5%</td>
</tr>
<tr>
<td>zones of zoning plan</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The treatment through GIS and the measures of the C index of data concerning environmental devices reveal the impact of such presumed factors of stability on the landscape. Most of the site is part of the Regional Park of Brotonne (these parks work in the fields of cultural and natural heritage conservation), and/or under POS (Plan d’Occupation des Sols) the municipal land use planning whose purpose is to manage the development of the municipality and to prevent the destruction of natural resources. Evaluating the effectiveness of such protection policies is realised by calculating the $C$ index of areas under protected zones and areas outside protected zones (Table 5). This measure reveals that the landscape organisation declined in both the protected and unprotected sectors but the decline for protected areas (9.7%) was less than for unprotected ones (24.5%). Some parts of the site are under ZNIEFF (Nature Heritage Inventory) whose purpose is to enhance natural landscapes showing special ecological interest. This last device (comparable to the SSSI in Great Britain, Sites of Special Scientific Interest) is not a protection tool but an evaluation of the ecological significance of rural areas or specific natural habitats. Measures of the $C$ index reveal that areas covered by the ZNIEFF classification went through a decrease of the landscape organisation but the decrease in such areas (16.7%) was less than the decrease in the others (20.6%).

4. Discussion

Change in a rural landscape and its driving factors can be studied through different methods (Forman and Godron, 1986; Wickham and Norton, 1994). The choice of the method of recording the information is determined by the type of results required. In the case of our study. The study on a plot basis of landcover dynamics or of landscape organisation (landuse versus natural habitat) proved very precise through the use of GIS.

The gridding method allows the crossing of data from different fields which are not necessarily arranged at the plot scale. Indeed, this systematic sampling does not focus on only one kind of data. Its advantage lies also in its capacity to assess landscape structures (grain, spatial diversity) of the microlandscape cells which are the cells of the grid. Ordination of these grided data provide clear and useful thematic cartography of the site.

The landscape organisation of this rural area was set according to the natural habitat pattern which defined constraints determining land uses (slope, soils as agricultural impediments). This organisation can still be observed today, despite the decrease of correlation between habitat and landuse features during the 25 year period studied. At the opposite, agricultural data exhibit an increasing correlation with some structural landscape features. This shows that the initial natural organisation is progressively turning into an ‘agricultural’ one. Clearly, some landscape changes (plot size and landuse changes) appear to be typical of specific farming systems and their dynamics. The dynamics of the St Martin landscape (disappearance of large bocage zones in the lowlands, apparition of intensive and sometimes large size crop cultures) would correspond to the following agricultural evolution (noted from the studies realised in these areas by Fruit (1991)): ‘milk dominant’ farmers who need important pasture areas for their cows have gradually left place to ‘meat dominant’ farmers who need less grassland but need more cropland which they produce for commercial purposes or for animal feed.

Fig. 8 helps to understand this phenomenon: The maximum of land diversity (here represented by land use evenness) corresponding to optimal mix of all habitats is a narrow range of landscape type (Green, 1989; Kovar, 1992). This range is always the result of increase of habitat diversity in an original situation of large homogeneous patches with little edge habitat, and usually develops into the final situation...
of small relictual patches and substantial formerly edge habitat (Grime, 1977). This has to be related to the biodiversity model where the optimum is at the middle of the gradient (Fig. 9).

The St Martin site is situated between the two large industrialised towns of Le Havre and Rouen, and less than 10 km away from the latter. This urban context also explains part of the landscape changes, such as the settlements observed on land left aside by modern agriculture (such as chalkgrassland), or on areas of easy access by road to Rouen. Moreover, the population of the four municipalities contained in the study area has little changed in number, but much in type. Their professional occupation has changed from first sector (agriculture) to tertiary sector (RGA, 1964–1989). This explains the urbanisation phenomenon observed on our site.

The analysis of the quality of ecological landscapes is one of the major aims of such environmental devices as the ZNIEFF. In that regard, it is interesting to note that the most remarkable ecological zones (ZNIEFF inventory) are characterised by a slower landscape dynamic. This could suggest the idea that protecting a landscape implies slowing
down its dynamic. Today, two protection tools at different scales are present on our site but the evaluation of their efficiency is delicate. The observed decrease in the landscape’s organisation, for instance, does not necessarily mean this tool is ineffective since it was only set up 10 years ago while the changes monitored cover the last 30 years. As concerns the impact of such tools as the Regional Parks, force is to notice a lack of global assessment of such policies on the rural landscape and if such areas appear ecologically richer, this is not necessarily the result of the designation as protected areas but maybe the reason for putting these areas under protection.

Changes of the St Martin site have tremendous impact on the ecosystem of this landscape. Such modifications as the large decrease of linear elements like hedges (which are species rich and connect otherwise isolated patches (Burel and Baudry, 1991) or the decrease of chalk grasslands (which are from the point of nature conservation interesting semi-natural landuse types and often relict habitat for endangered species (Dutoit and Alard, 1995) are responsible of the deterioration of the ecological structures of this landscape and thus a potential risk to the landscape biodiversity.

Acknowledgements

Dr Rob Lenders, Nijmegen University; Dr Luc Degolbery for assistance with GIS, Department of Geography, Rouen University.

References


