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Structure analysis of hedgerows and other perennial landscape lines in two French agricultural landscapes

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Abstract

Simulating landscape is a main issue for several domains and can be done on the basis of real data or of random spatial patterns. In ecology, these last approaches –also called neutral models, are mainly based on raster approaches. More recently, polygonal approaches have been developed to model vegetation patches or plot fields in agricultural landscapes. In this paper we focus on lines that structure the agricultural landscape, such as roads, irrigation ditches and hedgerows. Our more precise aim is to model hedgerows because of their role for numerous ecological and environmental processes. We investigate ways to characterize hedgerow structures and show results for two contrasting agricultural landscapes, one situated in south-eastern France (grown with orchards) and the second in Brittany (West of France, bocage type). In particular, we assess whether, and under what circumstances, the spatial distribution of hedgerows is structured by the position of more perennial linear landscape elements such as roads and ditches and the scale of such structures. First results show that hedgerow structures were dependent on perennial lines at short distance and that the neighbourhood of hedgerows is uniform beyond 150 meters. Furthermore different structures of neighbourhood were highlighted according to the main orientations of hedgerows in south-eastern France but not in Brittany.
Keywords: Agricultural landscapes, Brittany, Hedgerows, Provence, Spatial structure

1 Introduction

Modelling and simulating landscapes is a main issue for several domains, e.g. geography, ecology and agronomy. Landscape simulation is used for studying the influence of landscape patterns on ecological phenomena [11], or to study the links between human activities, landscape configuration and environmental problems [4]. Landscape simulation can be done on the basis of real data or on the basis of random spatial patterns. Random spatial patterns –or neutral models– are useful for three main reasons. First, real data are not always available or are too specific and thus reduce the scope of application of the model results. Second, in the case of anthropogenic landscapes, it is necessary to prospect new configurations in order to forecast their effects or to find out the best configuration with respect to the agro-ecological process in concern [6]. Finally, random landscapes can be used to test the sensitivity of process models towards the spatial variability of agricultural landscapes.

Neutral landscape models can focus on various objects at various levels. Neutral models used in landscape ecology are mainly based on raster approaches, land-use being allocated randomly to pixels and then clustered by various methods [9]. More recently, polygonal approaches, using geometrical tessellations, have been proposed to simulate patchy (agricultural) landscapes [5,8]. In these last approaches, real landscapes are characterized by a distribution of plot centroids that is used as a basis for building (Voronoï or rectangular) tessellations. These approaches allow modelling field patterns (polygons) with some control of their characteristics (e.g. average size). Landscapes, however, are not only made of polygonal elements but also of lines (e.g. hedgerows, field margins...) that are not always linked together in to networks.

While network analysis and simulation are major questions in spatial data analysis [10], few studies focused on simple lines and their spatial organisation. Most of the work has been about the relation between the hedgerows, ditches and the spatial distribution of animals [1] or plants [3]. In the present study we shall focus on lines that structure the agricultural landscape, such as roads, irrigation channels or ditches (thereafter all named ditches for simplicity) and hedgerows. Our more precise aim is to model hedgerows because of their role for numerous ecological and environmental processes [2,7]. The simulation of realistic hedge structures will be later integrated in models of agricultural landscapes in order to study landscape management of various agro-ecological processes.

This paper investigates ways to characterize hedgerow structures in agricultural landscapes and presents results for two contrasting French agricultural landscapes. The first landscape is in south-eastern France. It is mainly grown with pome fruit orchards, and has a dense cover of windbreaks and irrigation channels. The second landscape is in Brittany, West of France. It is characterised by a “bocage” type hedgerow pattern and the water network is mostly of ditches. In the present study, we shall, in particular, assess whether, and under what circumstances, the spatial distribution of hedgerows is structured by the position of more perennial landscape elements such as roads and ditches. We shall also assess the scale of such structure by considering neighbourhoods of hedgerows up to 500 meters .

2 Material and methods

2.1 Data sets

The analysis was based on two French datasets. The first set ('the low Durance valley') described an approximately 70 km² agricultural landscape in south-eastern France (coordinates in WGS84 system from 43°46'27"N to 43°51'23"N and from 4°51'12"E to 4°57'34"E). The main agricultural production consists of orchards, mostly pome fruit (apples and pears), and some vegetables. The region is characterized by a high density of windbreak hedgerows. The road and hydrological networks were provided by the French National Institute for Geography (BD TOPO®, IGN). All 11501 hedgerows were manually digitalized with ArcView (Version 9.1, ESRI) from an aerial photography (BD ORTHO®, IGN, 2004 – pixel size: 0.5 m) in the form of polylines.

The second set (Fig.2) describes an approximately 120 km2 agricultural landscape of Brittany (coordinates in WGS84 system from 48°25'32"N to 48°34'06"N and from 1°31'39"W to 1°39'07"W). The northern part of the area is made of large fields while the southern part is a typical bocage landscape of Brittany with a high density of hedgerows. The 7561 hedgerows were mapped by exhaustive field monitoring of a digitalized map of administrative parcel limits (Courtesy, Costel Rennes, France). The road and hydrological networks were provided by the French National Institute for Geography (BD TOPO®, IGN).

2.2 Data manipulation

To make data comparable in the two data sets, all hedgerows, roads and ditches were individualised by splitting polylines in unidirectional segments, meaning for example that two contiguous but perpendicular hedgerows were considered as two different elements. We thus obtained 14819 hedgerow, 9152 ditch and 43416 road segments in the Brittany landscape and 11557 hedgerow, 2014 ditch and 3737 road segments in the low Durance valley landscape. Each segment of hedgerow or other perennial element was then characterized by its length and orientation.

2.3 Selecting windows with various line densities

To characterize the heterogeneity of the two studied landscapes in terms of linear elements, we split them in windows of growing size (from 200 m x 200 m to 1300 m x 1300 m). We then plotted the distribution of the number of hedgerows and other linear elements per window, as a function of window size. From this distribution, we chose a window size (1100m x 1100m) with a sufficient mean and variance of the number of landscape elements (not shown). For this window size, we then plotted the correlation between the number of roads and the number of hedgerows (one point= one window) and we chose four situations resulting from the combination of two levels of hedgerow density (medium, high) and two levels of road density (medium, high). Windows with low levels of density were not taken into account since they were not typical for the considered regions. Windows situated on the edge of landscapes were excluded. Each focus window was associated to a target area made of this focus window and its 8 neighbouring windows

2.4 Analysis of hedgerow distribution with regards to perennial elements

To assess the possible influence of perennial linear landscape elements on hedgerows, in each focus window, for each hedgerow we assessed:

1. whether its closest neighbour was a hedgerow or another perennial element
2. whether its parallel or perpendicular closest neighbour was a hedgerow or another perennial linear element
3. the number of hedgerows or other perennial linear elements in areas surrounding each hedgerow relative to the average number of each element type expected in these areas. These areas were of increasing size, determined by a maximal distance to each hedgerow. We considered either all neighbours or only those parallel or perpendicular to each hedgerow.
4. the same procedure was followed as in (3) except that we considered separately the windbreak hedgerows and those that are perpendicular to them.

For this purpose, all neighbours were computed based on the distance between segments: for two S and S' segments, $d(S,S')=\min\{d(x,y)$, for all points x in S and all points y in S'$\}$. The number of neighbours of the S segment closer than distance d is $Nr(S,d) = |\{S' \mid d(S,S') < d\}|$. Numbers of neighbouring hedgerows ($Hr(S,d)$), roads or ditches were defined similarly.

For (3) and (4), the expected number of neighbours was defined for each segment and distance as follows. Let A be the surface area of the whole target area, HA the number of hedgerow segments (respectively roads, ditches) in this area. HA/A is the average density of hedgerows. The neighbouring area of a L-long segment at distance d was calculated as $B(L,d) = \Pi * d^2 + 2 * L * d$ (where L is the length of the segment). The local expected number of neighbouring hedgerows of a L-long segment closer than distance d was thus $Ht(L,d) = B(L,d) * HA/A$.

Furthermore, for a given segment, neighbours were classified following their angle with the segment direction: neighbours parallel to this segment were those forming an angle comprised in $[-\Pi/9; +\Pi/9]$ with the segment direction and neighbours perpendicular to this segment were those forming an angle comprised in $[7\Pi/18; 11\Pi/18]$ with it.

Finally hedgerows were separated into two groups, according to their direction:
in the low Durance valley: HNS hedgerows had an angle of [-20°;+20°] and HWE (windbreak) hedgerows had an angle of [60°;100°] with respect to the North-South line.
in Brittany angles with respect to the North-South line were [-20°;+20°] for HNS and [80°;120°] for HWE hedgerows.

3 Results and discussion

We shall first present a global description of the linear elements in the two study landscapes and show the diversity of situations within and between landscapes. We shall then

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Table 1: Number of elements in the chosen windows

Window	**Elts in focus window**	**Hedgerows**	**Roads**	**Ditches**	Elts in target area	Hedgerows	Roads	Ditches
D1_9	**236**	**148**	**19**	**69**	2035	1241	263	531
D2_2	**289**	**202**	**27**	**60**	2550	1949	186	415
D8_3	**266**	**208**	**33**	**25**	1936	1457	222	257
D8_9	**188**	**130**	**19**	**39**	2361	1711	158	492
B2_7	**595**	**179**	**28**	**388**	5426	1282	220	3924
B6_3	**651**	**137**	**81**	**433**	5183	1486	498	3199
B6_7	**789**	**299**	**96**	**394**	7226	2207	992	4027
B8_3	**1060**	**318**	**103**	**639**	8211	2789	616	4806

choose two examples to assess the global structure of hedgerows and their relationship to stable linear elements (roads and ditches).

3.1 Chosen windows and diversity of landscapes

Table 1 indicates the number of elements in the focus windows and target areas for the four windows chosen in the two regions. The low Durance valley is presented first (windows number D1_9, D2_2, D8_3, D8_9) and then Brittany (windows number B2_7, B6_3, B6_7, B8_3).

The number of hedgerows per focus window ranges between 130 and 200 in the low Durance valley and between 140 and 300 in Brittany. The number of roads ranges between 20 and 30 in the low Durance valley and between 30 and 100 in Brittany. The number of ditches is much more variable, from 25 in the D8_3 window up to 639 in the B8_3 window: whereas the number of roads and hedgerows are similar in the two regions, ditches are much more numerous in Brittany than in the low Durance valley.

In the following, we examine the maps of two focus windows, D8_9 and B6_7 (Fig. 1). These maps show that the structure of hedgerows in the low Durance valley is organized along the roads and hydrological networks, and mainly as alignments of windbreak (East-West) hedgerows. In Brittany, hedgerows are shorter, more irregular, and planted 'around' the plot-fields and pastures. Main directions are North-South and East-West.

3.2 Closest neighbours

Figure 2 presents the distribution of closest neighbours of the hedgerows in the four focus windows of the two regions for each type of linear element. Parallel and perpendicular neighbours were considered separately.

Hedgerows closest neighbours were mainly hedgerows in the two regions. Roads were more frequent neighbours in Brittany than in the low Durance valley, which is consistent with the higher relative number of roads with respect to hedgerows in Brittany. On the contrary, ditch neighbours are more frequent in some focus windows (D1_9, D8_3) of the low Durance valley than in Brittany although their number is very high in Brittany. Finally there were no obvious differences between parallel and perpendicular neighbours.

Figure 1: Two focus windows: D8_9 in the low Durance valley (up), B6_7 in Brittany (down)

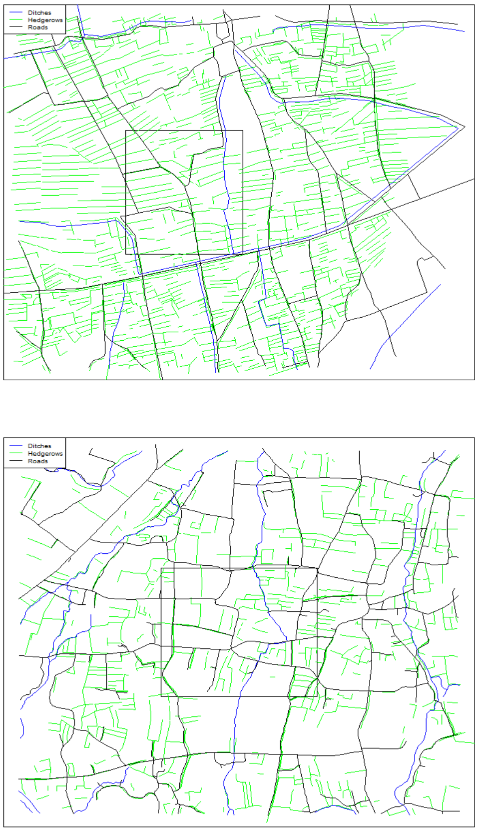
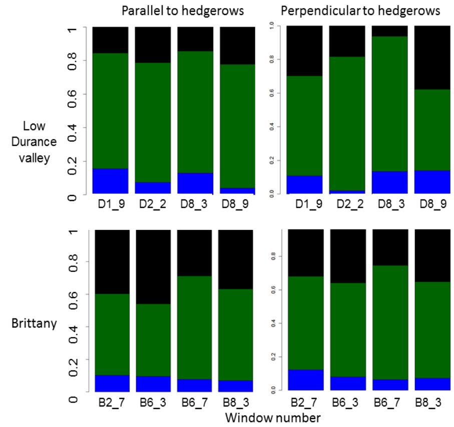


Figure 2: Distribution of hedgerow closest neighbours : proportion of ditches are represented in blue, roads in black, hedgerows in green.

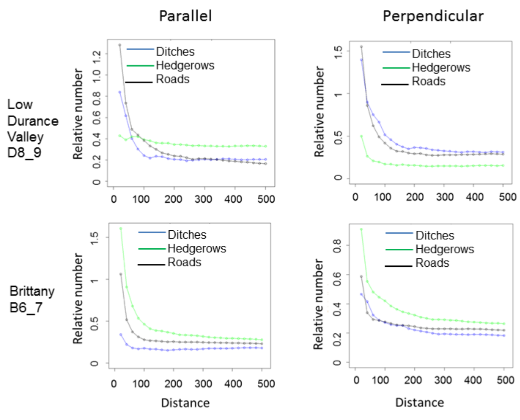


3.3 Neighbour distributions

Figure 3 presents the relative number of parallel and perpendicular neighbours of each type in increasing areas surrounding hedgerows. These graphs can be read in different ways.

First, a broad comparison can be made for a given window between the parallel and the perpendicular directions for each type of elements: relative values indicate if each type of element is usual found parallel or perpendicular to hedgerows. The threshold value at large distances provides the proportion of elements of one type that are either parallel or perpendicular to hedgerows. Then, considering only one type of element (e.g. ditches) in one direction (e.g. parallel) and one window (e.g. D8_9), the pattern indicates if this type of element is over-represented or not at some distances, with respect to its average density. Finally, comparisons of patterns between regions allow to assess if relationships between hedgerows and other landscape elements differ both in terms of orientation and in terms of distance for relationship.

Figure 3: Relative number of parallel/perpendicular neighbours according to their element type and distance of neighbourhood (m) for the D8_9 (up) and B6_7 (down) windows



Following the scheme of analysis proposed above, it can be seen that hedgerows are more frequently parallel than perpendicular to other hedgerows and, on the contrary, they are more frequently perpendicular than parallel to ditches and roads in window D8_7 . This is not the case in window B6_7 where no such pattern can be seen.

A striking result is that the relative number of all element categories (hedgerows, roads and ditches) almost always decreases in the 100 first meters towards the threshold providing the proportion of elements of one type that are either parallel or perpendicular to hedgerows. This indicates that all elements are over-represented at short distances from hedgerows, indicating short distance association between them. The only exception concerns the relative number of parallel hedgerows in D8_9. This number is almost constant, which is consistent with the apparently regular distribution of hedgerows on Fig.1. The over-representation concerns in particular hedgerows in window B6_7, showing a strong association between hedgerows, and it concerns mostly roads and ditches in window D8_9, showing a strong association between hedgerows and these elements at very short distance. The decrease of relative numbers of all elements is fast and after 150 to 200m the number of each element type is close the its average over the window in both regions.

3.4 Neighbour distribution according to hedgerow direction

Figure 4 represents the distribution of the relative number of parallel neighbours to HWE and HNS hedgerows according to their type and distance of neighbourhood (m). Comparing the neighbours of HWE and HNS hedgerows in the D8_9 window (low Durance Valley) highlights three main results : First, HWE hedgerows had a high (0.5) and constant relative number of parallel hedgerow neighbours with a peak at 100 m, consistent with the dimension of fields in this region. Roads and ditches were much represented at short distances (0.4) but their number decreased in the first 100 meters. Second, HNS hedgerows had a low (0.1) and almost constant number of hedgerow parallel neighbours. Third, roads were over-represented (2.0, compared with values at Fig. 3) at short distance of HNS hedgerows showing that these hedgerows are mainly located along the roads.

Contrarily, the distributions of neighbours of HWE and HNS hedgerows were similar in the B6_7 window (Brittany), except for the ditches, which were very few in the HWE parallel neighbourhood. Actually ditches are mainly oriented along the North-South line (see Fig. 1, down).

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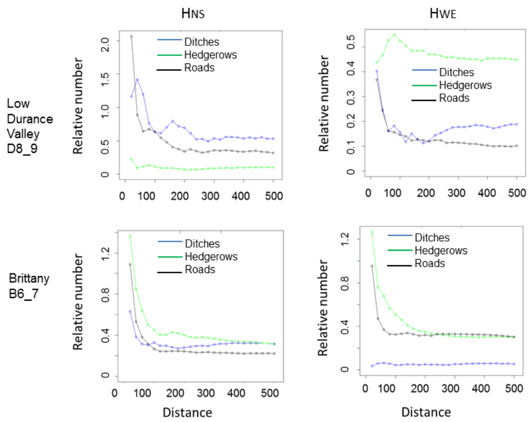
Figure 4: Relative number of parallel neighbours according to their type for the B6_7 (down) and D8_9 (up) windows, HNS (left) and HWE (right) hedgerows



3.5 Consequence for simulation of hedge structures

Previous results showed that the structure of hedgerows depends on perennial lines, especially on roads at very short distance (<20m). Roads may thus be used as a basis from which random hedgerow structures can be built. With this aim, we looked for the neighbours of roads. For each road segment, we thus computed the number of HWE and HNS in the parallel and perpendicular directions, and in a 20 m neighbourhood. Table 2 gives the average values computed on the four focus windows of each region.

Table 2: Number of HWE and HNS in the parallel and perpendicular directions, and in a 20 m neighbourhood of roads in the two regions (average value on the four windows).

	Low Durance valley		Brittany	
	parallel	perpendicular	parallel	perpendicular
HWE	0.25±0.16	1.09±0.48	0.25±0.10	0.24±0.06
HNS	0.37±0.12	0.13±0.10	0.38±0.19	0.16±0.11

In low Durance valley, each road segment has on average a perpendicular HWE hedgerow but the high standard error denotes variability between windows; Approximately one third of road segments are parallel to a close HNS hedgerow both in low Durance valley and in Brittany. In Brittany, half of the roads have a perpendicular or parallel HWE hedgerow in their 20m-neighborhood.

4 Conclusion

This paper presents a first step in our work for modelling the structure of hedgerows in agricultural landscapes. We studied therefore two contrasted landscapes, in the low Durance Valley and in Brittany. The dependence assumption between hedgerows and perennial lines (roads, ditches) was confirmed. Furthermore, we showed that the distance effect on hedgerows was limited to 100-150 m, suggesting that the modelling should be achieved at this scale. Finally, we examined the role of hedgerow direction, separating HWE and HNS hedgerows, and proved that modelling these two types of hedgerows separately was pertinent in low Durance Valley but apparently not in Brittany.

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