Spatially explicit farming system modelling for an efficient agri-environmental policy design

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Abstract

A mathematical programming model is developed and associated to a spatial pattern index (Ripley L-function) to analyse the optimal reserve design and implementation for the Little Bustard conservation in *Plaine de Niort.* The model structure corresponds to three spatial levels, fields, farm and landscape. Simple in terms of area representation it is detailed in term of farm behaviour and spatially explicit. The model is applied in a normative and in a positive way. The major findings of the normative approach relate to the trade-offs between the reserve pattern and its cost. It was found that the environmentally optimal reserve, which is randomly dispersed across the zone, is the most costly one. Within the positive approach, it is illustrated that the various reserve patterns generated within the normative approach can be obtained through relatively simple uniform contract structures. The most effective contract structure is a degressive set of two payments enabling all the farms to enrol at least a small share of their land.

Key words

Biodiversity, spatial optimization, mathematical programming, agri-environmental policies, Tetrax tetrax.

Acknowledgements

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1 Introduction

During the last fourty years, farmers have increasingly changed the use of their lands, and modified their farming techniques.

It appears that these changes have led to an important decrease in biodiversity. Considered the lack of standard measures of biodiversity, one indicator that has been proposed and largely studied is birds' population (Gregory *et al.* 2005). Agriculture intensification has been pointed out as one of the main reasons of the decline in Europe's farmland bird population (O'Connor *et al.*, 1986, Potts 1997, Chamberlain *et al.* 2000, Donald *et al.* 2001, Julliard *et al.* 2003).It has been shown that common farmland birds in Europe have declined steeply over the last two decades (by 25%), whereas woodland birds have not (Gregory *et al.* 2005).

The Little Bustard (Tetrax tetrax) used to be a common bird of open fields in most of Europe until the early 1900s, but has disappeared from most of its former habitat over the last century. In France the decline of breeding males in agricultural habitats increased dramatically during the last twenty years (by 92% since 1980) due to land use changes and to the intensification of agricultural practices (Bretagnolle and Inchausti, 2005). In 2000, most of the remaining population (420 breeding males) was located in Poitou-Charentes. Our research is focused on a core area of this region covering approximately 350 km^2 in *Plaine Niort*. *Plaine de Niort* has been traditionally dedicated to mixed farming but has recently undergone a rapid specialisation in crop production: the area in meadows and pasture dropped by 60% between 1988 and 2000 (Bretagnolle, 2004) and was replaced by annual crops (mainly wheat, maize, and recently, rapeseed). This induced a decrease in insect abundance and an increase in bird nest destruction during harvesting. Today, Little Bustards are seriously in danger.

This specific area was designated a Natura 2000 site to stop the decrease of the Little Bustard population. Within the framework of the CAP Rural Development Regulation, specific agri-environnmental schemes are currently implemented to encourage farmers to keep grasslands and to grow alfalfa using Little Bustard-friendly cropping techniques.

This paper presents a mathematical programming optimisation model called OUTOPIE (*OUTil pour l'Optimisation de PrairIes dans l'Espace)* and developed for this specific Natura 2000 site. Mathematical programming farm level models are recognized as a suitable tool for environmental-economic research (for a discussion on the issue see e.g. Wossink *et al*. 1992), and have been widely applied (e.g. Falconer and Hodge, 2001; van Wenum *et al*., 2004; Ekman, 2005; or Havlík *et al*., 2005). The originality of OUTOPIE is that it takes into account, in addition to the farm-level, two other spatial levels: field and landscape. Farmers' profit-maximizing behaviour as well as technical and administrative constraints influencing land management are accounted for at the farm level. The field represents the elementary unit which by its characteristics determines to a large extent the actual land use, and the landscape is crucial for our analysis because it is at this level that the protection of the Little Bustard occurs. The specificity of the landscape pattern that is considered suitable for an optimal Little Bustard conservation, i.e. 15 per cent of the zone covered with randomly dispersed grassland, obliges us to explicitly take into account the spatial distribution of fields and thus also requires using specific indicators capable to characterize this distribution.

The aim of our model is to explore where the Little Bustard compatible grasslands should be located so that the cost in terms of the farm income foregone is the lowest, and what agri-environmental policy should be implemented so that the target farms really participate and the desired landscape pattern can be provided. Therefore we will first explore the Little Bustard optimal landscape pattern and the trade-off between a deviation from the latter and the corresponding cost change, within the normative approach. Second, we will investigate different payment schemes susceptible to provide these landscape patterns and evaluate them in terms of the landscape pattern quality obtained and the budgetary expenditure due to compensation payments incurred, within the positive approach.

The paper is structured as follows: The methodology aspects concerning the analysis of the landscape pattern are covered in Section 2. In the following Section, the studied zone and the model are described. The results of simulations are analysed in Section 4. Finally, we provide a discussion of the adopted approach and of the obtained results as well as suggestions for further research in the Conclusion.

2 Spatial pattern analysis: Methodology

According to ecologists, the Little Bustard needs at least 15% of grassland plots throughout the site under study, 3 ha being the ideal size, randomly or regularly located within any radius between 100 and 1000m if the bird is to recover a normal productivity level[2]. We will refer to the plots of temporary or permanent grassland managed in a Little Bustard-friendly way, which is described in more detail in section 3.5, as to the *reserve*. Thus, to carry out a quantitative analysis of the optimal reserve design, we need to measure not only the size but also the shape of the reserve generated by the model. The former is straightforward, here we will focus on the measurement of the reserve shape. In this study, we used the Ripley L function to assess the spatial distribution of the reserve. The potential indices and the reasons of our choice are explained in the following paragraphs, as well as the basic principles of the Ripley L function.

[2] Information provided by V. Bretagnolle, CEBC, CNRS.

2.1 Potential landscape pattern measures

According to Ripley (1981), methods to analyse spatial point patterns can be classified into two broad categories: quadrat counts and mapped data. Quadrats are sample plots in a given area where measurements or "counts", such as population abundance or density, are made. Various indices were developed based on "intensity" counts in a set of quadrats, for instance, the variance to mean ratio, the index of clumping by David and Moore (1954) and the index of patchiness by Lloyd (1967). However, such methods do not efficiently account for the spatial pattern of points, for different patterns can lead to the same index value. The second category of methods is based on distance measurements between (all) individuals (bird nests, trees, etc.) on a map. The better known of these indices are based on the nearest neighbour distance and include the Clark and Evans (1954) index and test of randomness. However such indices do not account for spatial structures at different scales because they only consider the distance to the nearest neighbour.

The Ripley K and L functions (Ripley, 1981) combine both types of methods, i.e., quadrats (density counts) and distances, and account for spatial structures at different scales. They are widely used in plant ecology and can be used to study sedentary animals or stationary constructions (Haase, 1995). The requirements for a Little Bustard-friendly reserve being both in terms of fields density (15% of the fields covered with grasslands or alfalfa) and fields spatial distribution (a random or regular distribution of reserve fields within any radius of 100-1000m), the Ripley K and L functions seemed to us the most appropriate indices for the present study.

2.2 The Ripley K and L functions

The K function depends on the number of neighbours located within a distance r of each individual i in the study zone. Let A be the area of the zone studied, N the number of observed reserve plots, λ the density ($\lambda = N / A$), d_{ij} the distance between two reserve plots, I_r a counter equals to 1 if $d_{i,j} \leq r$ or to 0 otherwise, and w_{ir} an edge effects correction weighting factor. The expected number of further reserve plots within radius r of an arbitrary plot is given by $\lambda * K(r)$.

$$\hat{K}(r) = \frac{A}{N^2} \sum_i \sum_{j \neq i} (w_{ir} * I_r(d_{i,j})) \qquad (1)$$

$\hat{K}(r)$ is an unbiased estimator of $K(r)$. If the fields dedicated to the reserve are randomly located, following a Poisson distribution, then the expected value of $K(r)$ equals πr^2. According to Haase (1995), $\hat{K}(r)$ is calculated for many values of r and is tested against the null hypothesis of Complete Spatial Randomness (CSR of Diggle, 1983). However, like most authors, we adopted a derived sample statistics (Besag, 1977, Ripley, 1981), which have an expected zero value for all r under the null hypothesis of CSR:

$$L(r) = \sqrt{\frac{K(r)}{\pi}} - r \qquad (2)$$

Results can be interpreted as follows (c.f. Figure 1 for two spatial distributions of the reserve and Figure 2 for the associated values of L):
a) if the L function remains within the confidence envelope (dotted lines in Figure 2) then the reserve fields' spatial pattern is significantly (Poisson) random (pattern a) in Figure 1),
b) if the deviation from zero is significantly positive, i.e., L is above the upper limit of the confidence envelope, then the spatial pattern is clustered or aggregated (pattern b)).
The scale of interest and the intervals between radii depends on the specie and on the issue which is addressed. In our case, the analysis of the Ripley L function should be limited to the Little Bustard relevant radii ranging from 0 to 1km, and to intervals equal to the distance between two fields.

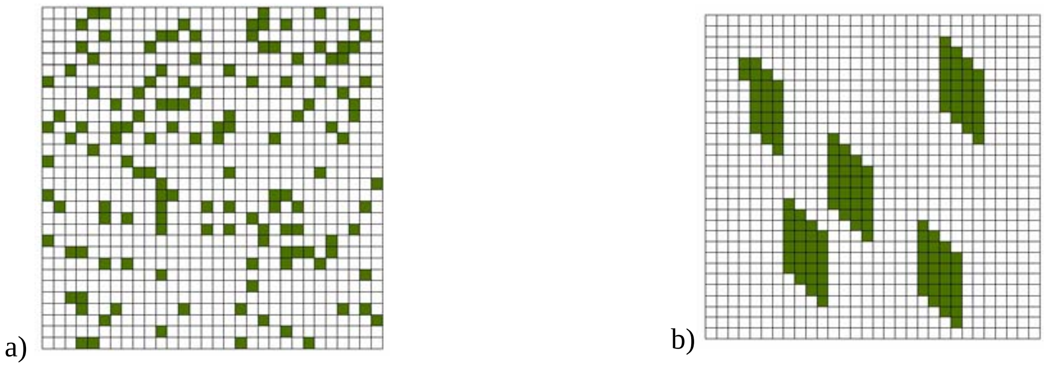

Figure 1. Examples of the spatial distribution of 135 reserve plots on a 900 plots grid: a) random, b) aggregated.

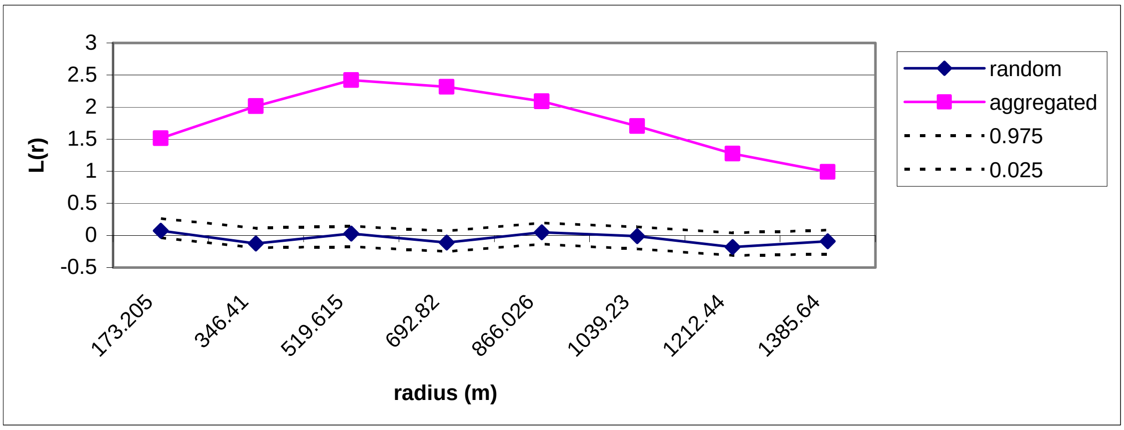

Figure 2. Ripley L function for an aggregated and a random spatial distribution of the reserve (c.f. Figure 1).

3 Model description

We first describe the studied zone on which OUTOPIE has been applied. Then the general features of the model are introduced and the crop and mixed-dairy farms characteristics are further detailed. Finally we explain how the notion of reserve and the Ripley L function were implemented in the model.

3.1 Studied zone

The site under study is part of *Plaine de Niort*, a plain dedicated to crop production which is located in a French region named Poitou-Charente. The studied site measures 350 km^2 and is composed of 450 farms and 11000 fields. It has been followed since 1994 by researchers of CNRS-Chizé. The great majority of the site was classified "special protection zone" (Zone de Protection Spéciale, ZPS) in 2003 within the framework of the Natura 2000 program. There are three main types of soils[3] in the site, based on geomorphologic and pedological features: deep plain soils in the north, shallow plain soils in the south and calcareous valley across the plain. Both plain soil types can be irrigated.

In our study, we have chosen to implement the model with a simplified map (c.f. Figure 3) of the site because we found it more relevant to study farms' behaviour and the reserve formation process on a stylized zone rather than on the real site which is very complex. We considered a 2,700 hectares zone divided into 900 fields, each of 3 hectares which corresponds to the ideal size of plots for the Little Bustard. The three main groups of soils were represented on the map, according to the ratio and layout observed in the real site. We represented 18 farms of 150 hectares each: 12 crop growing farms and 6

[3] Soil groups characteristics were provided by E. Sauboua, EGC, INRA Grignon.

mixed dairy farms (hatched on Figure 3). Both types are located on all types of soils and some of the farms have the possibility to irrigate a fixed set of contiguous fields (red plots in Figure 3), for irrigated fields are usually contiguous and close to a watering place. Irrigation is not common on calcareous valley, so we did not allow it.

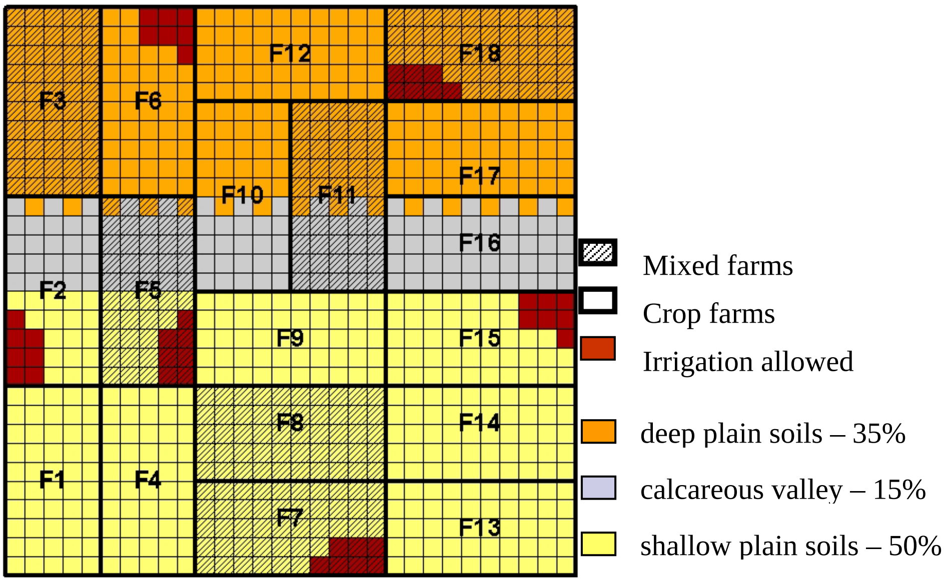

Figure 3. Simplified representation of the study area used in the model.

3.2 OUTOPIE

OUTOPIE is a mixed integer linear programming model. The model maximizes the sum of all farms' gross margins, subject to resource availability, technical and policy constraints. The prices are exogenous and there is not interdependence between the individual farms. Thus the result of maximisation of the sum of all gross margins is equivalent to the sum of gross margins maximised for each farm individually, and the optimisation procedure reproduces the farmers' profit maximising behaviour.

As stated above, the model accounts for three spatial levels: the field, the farm and the landscape at the regional level. The field represents the elementary unit of the model. Field characteristics, such as soil, climate and slope, determine the potential agricultural activities and cropping techniques that can be chosen by the farmer as well as the resulting yield and gross margin. In our model fields are characterised by their soil type, whether or not they can be irrigated and to which farm they belong. The farm is the level at which decisions concerning land allocation are made, taking into account regulation and policy constraints (milk quotas, obligatory set aside etc.), and technical constraints such as feed requirements. Finally, spatial relationships between fields constituting the landscape are accounted for at the regional level.

3.3 Crop farms

This model accounts for all the major crops (wheat, winter barley, sunflower, rapeseed, maize, and sorghum), for permanent as well as temporary grasslands including alfalfa, and for set asides. Crops are declined in different cropping activities i) depending on the preceding crop (5 types of wheat), ii) on crop use (maize and maize silage), iii) on the duration of perennial crops (alfalfa cultivated for 3 or 4 years) or iv) on the cropping technique (rain fed or irrigated). These crops are combined in crop rotations on the basis of information about the current practice, or new rotations are constructed so that they could be eligible for agri-environmental programmes or used to diversify the cattle feedstock, on each of the soil types. The number of represented crop rotations amounts to 52. The advantage of accounting for crop rotations instead of individual crops is that the former enables to take better into account the preceding and following crop effects on yields, input consumptions (nitrogen balance for instance) and environmental impacts. Crop rotations were provided by agronomists and local experts involved in the PRAITERRE project. Apart from alfalfa and grassland[4], crop yields were evaluated for each type of soil, taking into account the preceding crop effect, with a tool named PERSYST. PERSYST is being developed within the framework of PRAITERRE to assess cropping systems[5]. Crops production costs were determined based on FADN data and regional database. Thus on a crop farm, the basic decision variable is the share of each field allocated to a specific crop rotation.

The Common Agricultural Policy implemented in the model is based on the Luxembourg Agreement of 2003, with a set-aside rate set to 10 percent and single payments calculated with local references. The set of crop prices used to calculate rotations' gross margins is based on data from the 2005 FADN, Centre d'Economie Rurale, Poitou-Charente, and experts.

3.4 Mixed farms

In *Plaine de Niort* dairy cows are usually held on mixed farms partially involved also in crop production which is in the model represented as described above.

The dairy cattle breeding module of the model is derived from the OPT'INRA model, initially developed for suckler cow breeding (Veysset P., Lherm M. and Bebin D., 2005) and adapted to dairy cows in Poitou-Charente within the framework of the PRAITERRE project by LEE INRA Clermont-Theix. The module accounts for 18 animal types (3 types of cows, 4 types of calves and 11 types of heifers), differentiated by age, state (pregnant, dry, nulli/primiparous) and feed requirements. The year is divided into 3 seasons (winter, spring and summer) for cows: in winter their rations are based on conserved forage, in spring and summer it is possible to graze. For each type of animal, and for each season, several alternative feed rations are available. Some are based on local practices and the others were composed with the use of INRATion software [6] [7] (Agabriel et al, 1999, Jarrige, 1988). In both cases the corresponding milk production is determined according to the feed ration used. There are 80 rations on the whole. They are largely based on forage crops grown on the farm but can be complemented with concentrates. Rations can be composed of 7 forage types (grazed grass, grass hay, grass silage, alfalfa hay, maize silage, cereals, and cattle-cake).

Dairy farms optimize crop rotations as well as the herd size and composition, the choice of feed rations, the purchase of concentrates, and the purchase or sale of forage crops. They are subjected to constraints such as milk quotas and cattle demography. The link between the herd size and milk production is made by feed rations. Decoupled premium for animals were introduced. Production costs and prices for milk and animals were provided by Institut de l'Elevage, Poitou-Charente, for 2005[8].

3.5 A Little Bustard-friendly reserve and its pattern

In the studied zone, an agri-environmental programme – designed and implemented by the local authority in collaboration with CNRS Chizé and whose principal objective is to conserve the Little Bustard population – already exists. This program is part of a "Contract for Sustainable Agriculture" (Contrat d'Agriculture Durable). In the model we consider that all land use types eligible for this agri-environmental program may constitute the reserve. These land use types are: permanent grasslands, temporary grasslands and alfalfa fields, all of them managed in compliance with some precise restrictions. Concerning permanent and temporary grasslands, the programme requires that the

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[4] Information on alfalfa and grassland managements was provided by Myriam Laurent, UEFE,INRA Lusignan.
[5] Persyst is developed by Laurence Guichard, UMR Agronomie INRA -Grignon.
[6] Local practices for rations were provided by Institut de l'Elevage (Poitou-Charente) and data were computed and adapted by M. Lherm and J. Legarto, LEE, INRA Clermont-Theix.
[7]For more information on the software http://www.inration.educagri.fr
[8] « Des references pour le conseil et la prospective : Systèmes bovins lait en Poitou-Charente », Institut de l'Elevage.

nitrogen fertilisation is limited to 60 N units per hectare, animal density is not allowed to exceed 1.4 livestock units per hectare and the first cut can take place only after May 1st. The main restriction on alfalfa fields is that mowing is forbidden between May 15th and July 31st, which makes the farmers loose a quantity of hay corresponding to one cut. Farmers – either crop growing or cattle breeding – have the possibility to receive a compensation payment if they enforce these Little Bustard-friendly cropping techniques.

The aim to analyse precisely the spatial pattern of the reserve requires two adjustments of the model structure presented so far. First, as we are interested in the precise location of each field involved into the reserve, we cannot allow that only a part of the three-hectare fields – which we account for in a spatially explicit way – is enrolled into the reserve. Therefore the decision variables which express whether a field is in the reserve or not have to be binary. Second, in order to observe the reserve location over the time, we added an index to each reserve relevant rotation, indicating at which stage the rotation starts. Crop relevant rotations actually last up to 11 years and temporary grassland and alfalfa represent three to five years within them. Let us consider a crop rotation including alfalfa which lasts 10 years (c.f. Figure 4). It can start either by crop n°1, n°2 …or n°10. The model as presented above would just give the fields where this crop rotation – involving alfalfa managed in compliance with the Little Bustard requirements – is located. It would not provide the information on the stage at which this rotation is in the individual fields and we would not know where alfalfa actually is. Thus, we have declined this rotation, and all the other Little Bustard relevant rotations with respect to their duration, in ten crop rotations depending on the first crop rank.

Crop rank	1	2	3	4	5	6	7	8	9	10
Rotation	alfalfa	alfalfa	alfalfa	wheat	rapeseed	wheat	sunflower	wheat	rapeseed	wheat

Figure 4. Example of a crop rotation including alfalfa.

The various policy measures tested in our scenarios, among which compensation payments, are supposed to influence farmers' behaviour and have an impact on the size and location of reserve plots, which we decided to assess with the Ripley L function as presented in Section 2. This spatial pattern analysis index is calculated after the optimisation, for it is non-linear which would further complicate the resolution of the mixed integer model. We had to deal with two issues: the first being the edge effect correction to avoid any bias in the function values and the second the generation of confidence envelopes to allow the interpretation of the function.

The issue of edge effect is raised when the distance between a reserve plot *i* and the nearest zone boundary is smaller than the considered radius *r*. In such a case the number of neighbours of *i* cannot be evaluated without bias. We had the choice between three edge effect correction methods compared and commented by Haase (1995): the addition of a buffer zone around the site under study, toroidal edge correction and edge correction by a weighting factor applied to the number of neighbours $I_r(d_{ij})$. We have chosen the latter, for the buffer zone is too data consuming, even if it is the most realistic method, and the toroidal method entails duplicating the study area around itself, which is a potential source of error. We have implemented a weighting factor inspired from the one of Getis and Franklin (1987) cited in Haase (1995). It is based on the assumption that the density and distribution pattern of neighbouring areas outside and inside the site boundary are the same. Our weighting factor w_{ir} is equal to the inverse of the proportion of the area of the circle of radius r and centered on plot i, which lies within the site boundary[9].

$$w_{ir} = \frac{\pi r^2}{\text{circle area within the boundaries}} \qquad (3)$$

[9] To have more information on the calculation of the weighting factor, please contact Laure Bamière (lbamiere@grignon.inra.fr)

Once the $\hat{L}$ function is assessed for the spatial distribution of the reserve in a scenario, it has to be tested against the null hypothesis of CSR. We used the Monte Carlo method to create a confidence envelope corresponding the number N of fields dedicated to the reserve in this scenario. For that purpose we simulated N randomly-generated reserve fields on the grid, following a Poisson distribution[10], and we calculated the $\hat{L}$ function for the same set of radii as the one used in the scenario. We repeated the procedure a thousand times and defined the bounds of a 95% confidence envelope for $\hat{L}(r)$.

4 Illustrative application

The strength of the presented model consists in its suitability for both normative and positive applications, where the normative application is used to find the most cost-efficient solution given the environmental constraints for the reserve design problem, while the positive application is used to test the agri-environmental schemes against the farmers' responses and thus to set up the schemes in a way which ensures that the desired reserve size and shape will be obtained. The purpose of the present section is to illustrate these two possible applications.

4.1 Normative approach

The optimal reserve from the conservationists' point of view corresponds to 15 per cent of the area covered with grasslands, the grassland fields being randomly located throughout the zone within any radius ranging from 100 to 1000 meters and managed in accordance to environmental restrictions as described in sub-section 3.5. Within the normative approach, we introduce these requirements into the model as additional constraints. The model based on maximisation of the sum of the individual farms' gross margins determines then the location of the reserve which minimises the cost. Here the cost is constituted to a large extent by the opportunity cost resulting either from substitution of some cash crops by grassland, or from lowering the intensity of grassland use.

Constraining the size of the reserve is straightforward. As explained above, grassland managed in the Little Bustard-friendly way is explicitly defined as a special activity; hence it is sufficient to control that the area of this grassland amounts to at least 15 per cent of the zone. The shape of the zone would be ideally controlled by a constraint explicitly ensuring that the value of the Ripley L function remains within the confidence envelope for all the relevant radii. This precision and methodological convenience would be at the expense of a considerably increased model solution complexity. Therefore we were looking for some proxy constraints which would enable to impose the environmentally optimal landscape pattern and still keep the model linear. We found that in the studied case, the environmentally optimal spatial distribution can be obtained through a constraint requiring that all farms contribute equally to the reserve, enrolling 15 per cent of their land[11]. The resulting landscape is depicted in Figure 5.

[10] The random generation program was kindly provided by Benjamin Boisteau, CEBC, CNRS-Chizé, France.

[11] As only whole fields can be enrolled into the reserve, and 15 per cent corresponds to 7.5 fields, some farms enroll actually only 7 fields and some farms 8 fields. Similar situation will occur also for some scenarios analysed later.

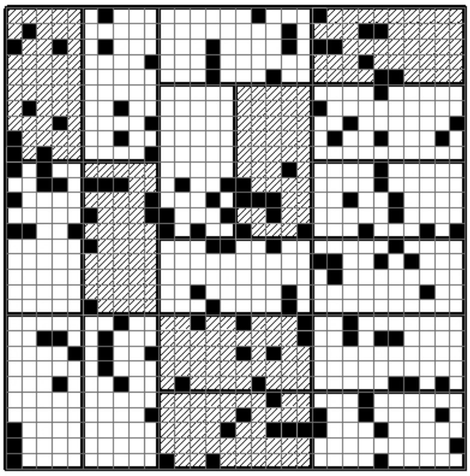

Figure 5. Environmentally optimal reserve location.

The test of the environmental optimality of the reserve presented in Figure 5 is given in Figure 6. There we can observe that if 15 per cent of each farm is enrolled in the reserve the values of the Ripley L function lie within the confidence envelope for all the Little Bustard relevant radii, indicating that the grassland distribution can be considered as random, and thus optimal, providing a benchmark for further analysis.[12]

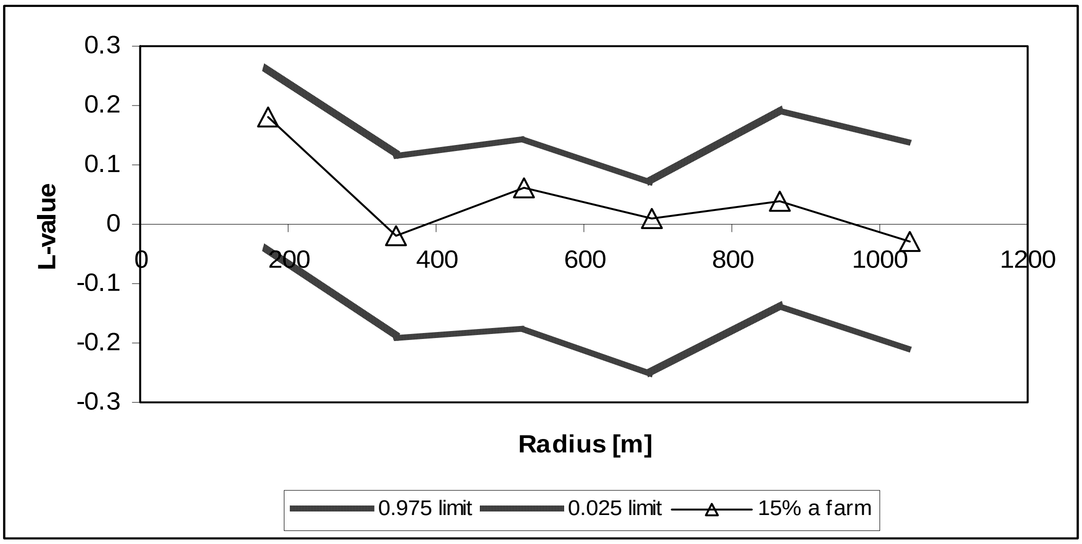

Figure 6. L-function values of the environmentally optimal reserve pattern.

The cost of the reserve can be calculated by the model as the difference between the total gross margin obtained when no reserve is required, and the gross margin obtained when the reserve subject to the size and shape constraints is to be provided. The cost of the environmentally optimal reserve calculated in this way is 258 000 euros, which represents 10 per cent of the total unconstrained gross margin. The average cost per hectare of the reserve is then 640 euros. But the cost of the reserve differs from farm to farm. The mixed farms on the shallow plain soils exhibit the lowest average cost per hectare – 35 euros per hectare. They manage a part of their grassland in a Little Bustard- friendly way even if the reserve is not imposed. The expansion of this management on a few additional hectares does not require any changes in the dairy herd size or structure; there is only a small decrease

[12] More precisely, Figure 5 represents the solution for the first year. During the controlled period, which corresponds to the length of the longest rotation, 11 years, the reserve will change its shape within each farm because the temporary grasslands are in the modelled rotations at most five successive years, then they are replaced by other crops. The tests carried out for the other years are not reported here but they show that the L-values for all of them are close to each other.

in the cropland area (around 5 per cent) and an increase in purchases of concentrated feedstock, by 1.5 tons per farm. Crop farms on the very fertile deep plain soils are on the other extreme concerning the reserve cost. They have to replace part of their cash crops by grassland which makes them loose 18 per cent of the gross margin.[13] Their average cost thus amounts to more than 1 100 euros per hectare. In general, the average cost per hectare of the reserve does not exceed 220 euros on livestock farms, and it does not fall below 850 euros on crop farms.

The considerable differences in the reserve cost among the different farms indicate that the environmentally optimal reserve will also be the most costly one; if the "low-cost" farms were allowed to provide a larger part of the reserve and the "high-cost" farms could decrease the part of the reserve on their land, then a reserve which would still cover 15 per cent of the total zone would cost less. We consider here two options of relaxing the reserve pattern optimality constraint (15 per cent per farm). First, the maximum share of land enrolled into the reserve by a farm, which is higher than 15 per cent, can be given. In this case some farms may not participate in the reserve at all. Second, the minimum share of the land enrolled into the reserve by each farm can be given. In these two relaxed scenarios the whole normative sense of the model as a site selection tool becomes obvious because the distribution of the reserve across the farms is no longer completely fixed, and the model has to find the reserve location minimising the total reserve cost.

Figure 7 shows how the cost efficient location of the reserve changes when we allow a farm to enroll up to 20, 30, 40 and 50 per cent of its land into the reserve. Even a slight increase of the maximum farm participation from 15 to 20 per cent causes that the reserve disappears from the highest cost farms – crop farms on the deep plain soils, Figure 7a. Further relaxing the maximum farm participation constraint leads to progressive concentration of the reserve on mixed farms. Above the limit of 50 per cent per farm, the cost-efficient distribution of the reserve does not change.

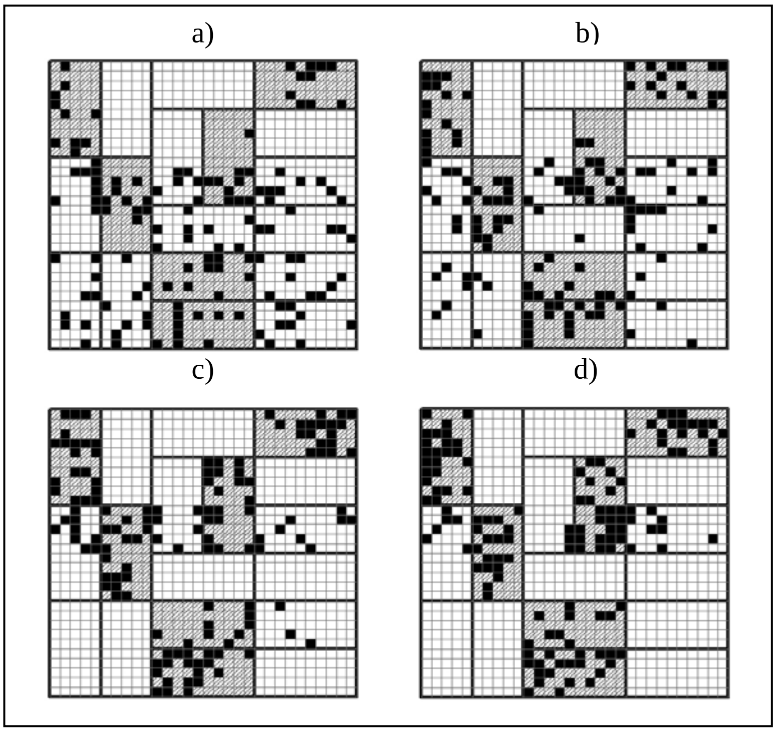

Figure 7. Reserve location when the maximum share of each farm enrolled into the reserve is limited to a) 20 per cent, b) 30 per cent, c) 40 per cent and d) 50 per cent.

[13] The crop farms constitute the imposed reserve through alfalfa temporary grassland. They could theoretically sell the alfalfa hay to livestock farms and thus improve their gross margin by some 600 euros per hectare of the reserve (yield 5 tonnes per hectare and alfalfa price 120 euros per tonne). But for various reasons, e.g. a preference for self-produced hay on livestock farms, this practice is not generalised in the studied zone. Thus we make here the assumption, that the grassland product from crop farms is not commercialised.

The visually apparent aggregation of the reserve is confirmed also by the values of the L-function, Figure 8. The only reserve for which all the values lie within the confidence envelope remains the one we identified above as the environmentally optimal one. Even if the share of the area of each farm which can be enrolled into the reserve is limited to 20 per cent, the L-values for all the Little Bustard relevant radii lie above the confidence envelope, indicating that this reserve is too aggregated for the Little Bustard. Relaxing the maximum share constraint then further deteriorates the quality of the reserve pattern.

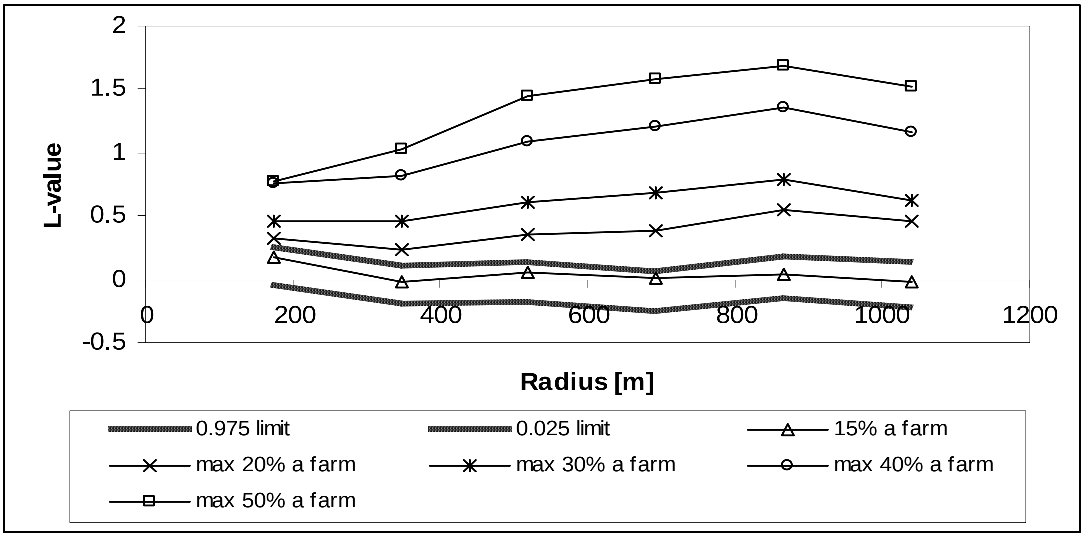

Figure 8. L-function values for different maximum shares of a farm allowed to be enrolled into the reserve.

The environmentally optimal reserve may not be the optimal one from the economic point of view. A complete cost-benefit analysis is beyond the scope of our study but the Figure 9 gives at least the information about how the cost of the reserve changes as its shape deteriorates. The worst shaped reserve costs some 40 per cent less than the environmentally optimal one. On the other hand, relaxing the maximum participation constraint from 40 to 50 per cent of the farm does not enable any cost reduction, though it further deteriorates the reserve pattern. Thus, the 50 per cent variant could probably be eliminated from consideration. The final selection of the "right" pair of the reserve pattern and the corresponding cost will be subject to the weights given to each of these parameters by the involved decision makers.

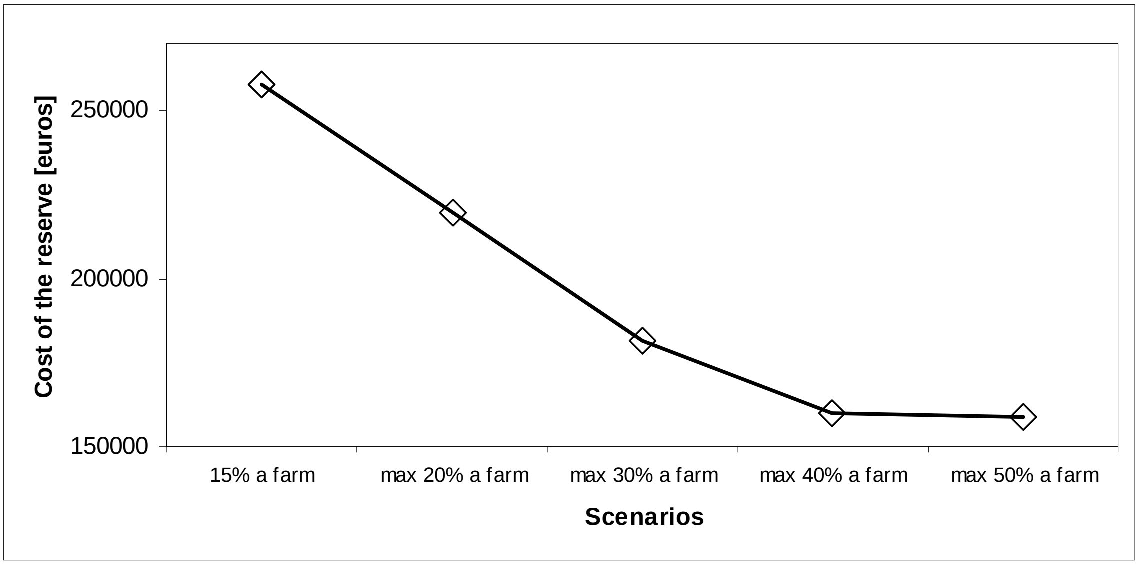

Figure 9. Cost of the reserve for different maximum shares of a farm allowed to be enrolled into the reserve.

Alternatively, the reserve shape constraint can be relaxed by setting up the minimum share to be enrolled into the reserve by each farm below the 15 per cent, the rest of the reserve can then be provided by the “low-cost” farms. We carried out alternative simulations requiring that at least 5 or 10 per cent of each farm is involved into the program. Figure 10 shows how the cost efficient reserve location changes when we oblige a farm to enrol at least 5 or 10 per cent of its land in the reserve. Figure 11 shows how the reserve pattern deteriorates (aggregates) as the minimum share to be enrolled by each farm decreases. The cost of the reserve decreases to 204 000 euros and to 171 000 if the minimum participation constraint is set to 10 and 5 per cent of each farm, respectively. Interestingly, when compared with the results for the first two least relaxed maximum participation limits, this cost is slightly lower (with the maximum participation constraint of 20 and 30 per cent of a farm the cost was 219 000 and 181 000 euros respectively), while the corresponding L-values are closer to the confidence envelope. Thus it seems that it would be more cost-efficient to constitute the reserve by including at least a small part of each farm and allowing somewhat higher participation of the low-cost farms, rather than to limit the maximum participation and to allow some farms not to participate at all.

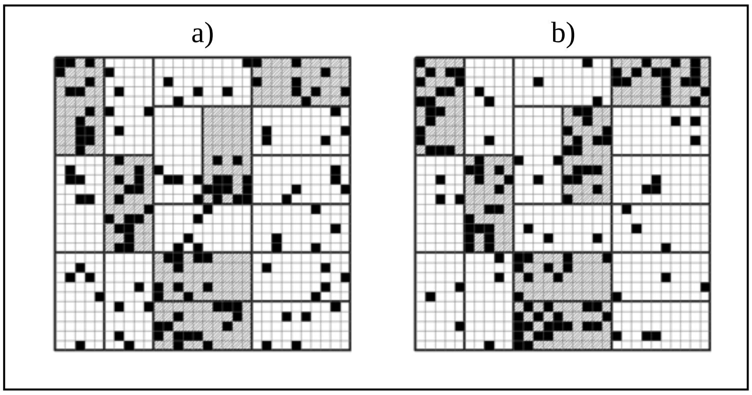

Figure 10. Reserve location when the minimum share of each farm enrolled into the reserve is limited to a) min 10 per cent b) min 5 per cent.

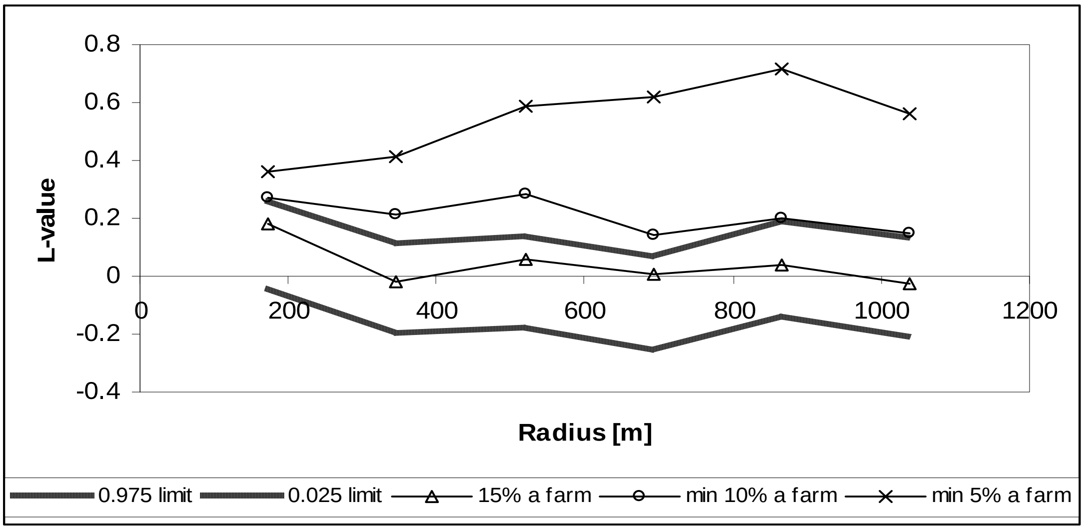

Figure 11. L-function values for different minimum shares of each farm obliged to be enrolled into the reserve.

4.2 Positive approach

We have considered so far the normative approach, where the model shows us the form of the reserve and where it should be located so that the cost is minimized. Until now, we have not considered the implementation issue. The normative approach supposes that we have complete information about each farm, especially about its cost of compliance with the reserve requirements, and thus we can go to each farmer and propose him a contract which determines the area he should enrol into the reserve, as well as the payment which will compensate the farmer precisely for his cost of the reserve. Then a gross margin maximising farmer is indifferent between whether to continue the former way of land management or to accept the requested reserve area on his farm., We usually make the assumption that the farmer is altruistic and thus will in such a situation accept the contract. As mentioned in Section 3.1, the studied zone contains 11 000 fields and 450 farms. The administrative cost due to information gathering and negotiation would probably make the implementation of the normative approach too costly. Therefore, agri-environmental schemes usually propose a uniform, non-differentiated across farms, payment per hectare of the reserve to all farmers and let them choose the area they want to enrol. Within this approach, it can happen that payments are too low and the area enrolled into the reserve is too small, or payments are too high and the reserve is too big and the program too expensive. The compensation payment can be of course adjusted later to correct these errors but such adjustments can be costly as they encourage farms to engage into strategic behaviour in the future. The same uncertainty exists with respect to the reserve shape. Hence, it is useful to first test the payment schemes by means of a model. This is precisely the domain of the positive model application. In this sub-section we will first solve the model with the actual agri-environmental payments for the contracts presented in Section 3.5, and then search for the contract schemes which would enable to obtain, or approach, the environmentally optimal reserve presented in Section 4.1.

The actual agri-environmental payments for the reserve are differentiated according to the land use type: 91.5 euros per hectare of Little Bustard-friendly managed permanent grassland, 110 euros per hectare of temporary grassland and 450 euros per hectare of alfalfa. Figure 12 shows the reserve resulting from gross margin maximisation by each farm without any minimum or maximum constraint concerning the share of the farm which should be enrolled. This reserve covers 6 per cent of the zone which is far below the Little Bustard requirements. Not surprisingly, only mixed farms participate in the reserve. We have calculated for the environmentally optimal reserve that the average cost is higher than 850 euros per hectare for all crop farms. As the marginal cost on crop farms is nearly constant – they just replace the given part of the cash crops by alfalfa – it is approximately equal to the average cost for any reserve area, and thus cannot be compensated by the proposed 450 euros payment. On the other hand the average cost of some mixed farms is well below 100 euros, and most importantly the marginal cost on these farms is increasing. Therefore even the farms which have an average cost of the reserve higher than 110 euros when they have to enrol 15 per cent of the land, still find it interesting to enrol some hectares for the payments proposed for the temporary and permanent grassland. This result corresponds well to the situation observed in reality, where only very few crop farms participate in the reserve and the average share of the mixed farms enrolled into the programme does not exceed 20 per cent of their land.

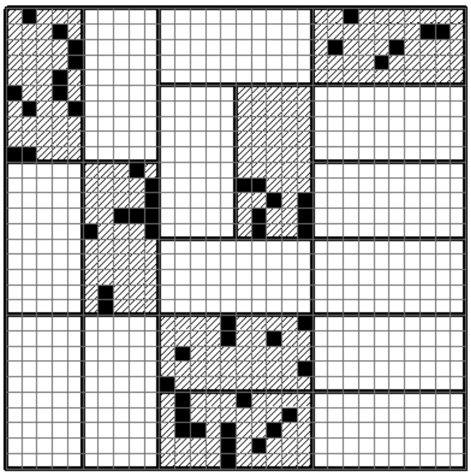

Figure 12. Model generated reserve location with agri-environmental payment levels actually applied in the zone.

Not only the size of the reserve obtained through actual payments but also its shape does not correspond to the Little Bustard requirements. As Figure 13 shows, the obtained zone is from the Little Bustard point of view highly aggregated.

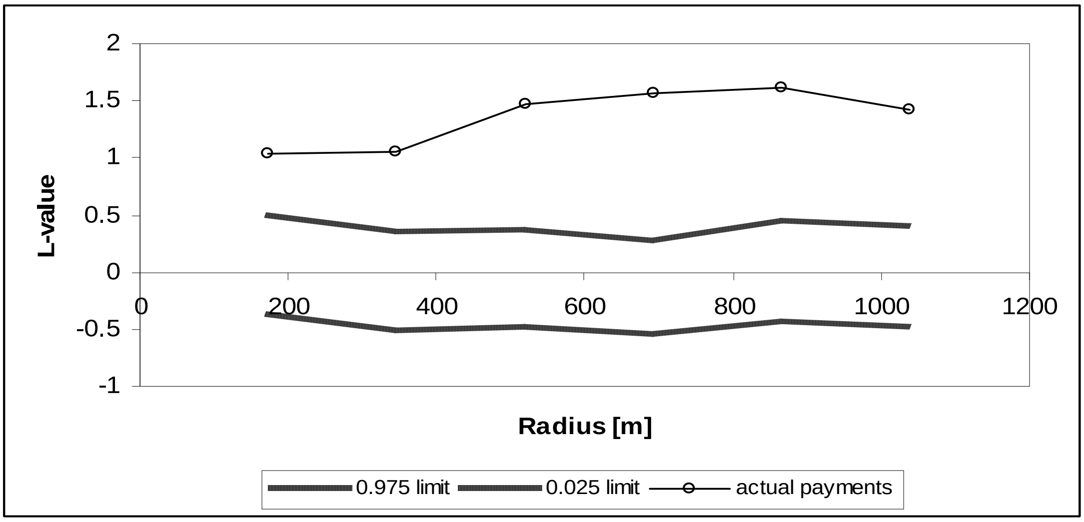

Figure 13. L-function values for the reserve generated by the model with agri-environmental payment levels actually applied in the zone.

In the rest of this Section we explore possible ways to approach the environmentally optimal reserve size and shape. The simplest payment scheme would consist in proposing a uniform payment for each hectare enrolled into the reserve. Using the model, we calculated that a payment of 860 euros per hectare of the reserve would be necessary for the farmers to enrol all together 15 per cent of the zone into the reserve. The cost of this programme would be by 35 percents higher then the cost of the optimal reserve calculated within the normative approach, 348 300 euros. This difference arises because with a uniform payment we pay all the farmers the cost of the last, most expensive, hectare enrolled into the reserve. The map of this reserve closely corresponds to the picture 7d, and the L-function values to those reported in Figure 8 for the scenario where maximum 50 per cent of a farm can be enrolled into the reserve. Thus although this reserve has the desired size, it is not acceptable because of its highly aggregated pattern.

The model enables to determine also a payment scheme which would encourage the farmers to enrol areas resulting in a reserve similar to that one when the maximum share enrolled into the reserve by a farm is limited to 20 per cent. In this case the contract can be formulated as a uniform compensation payment per hectare of the reserve up to the 20 per cent of a farm, and zero payment for any hectare enrolled above this limit. Using the model, we tested different payment levels to find the payment necessary for 15 per cent of the zone being enrolled into the reserve within this contract scheme. The results show that 880 euros per hectare would be required. The cost of the programme will then be 356 400 euros. The reserve pattern is similar to the reserve where maximum participation constraint is set to 20 per cent, see Figure 7a and Figure 8.

The contract scheme able to ensure the nearly optimal reserve, which we obtained within the normative approach by fixing the minimum share enrolled into the reserve by each farm to 10 per cent and the total reserve area to 15 per cent of the zone, see Figure 11, would require a slightly more complex structure. A set of two payments is to be designed; for a limited share of each farm a higher per hectare payment is offered, but above this limit still a payment, although substantially lower, can be obtained. We found that a payment of 1 125 euros per hectare up to 10 per cent of a farm, and another payment of 400 euros per hectare above this limit, are necessary. The cost of this programme which leads to the nearly optimal reserve pattern is then 357 750 euros.

Finally, even the environmentally optimal reserve pattern can be obtained when paying 1 125 euros per hectare up to 14 percents of each farm and 170 euros per hectare above this limit. The cost of this program would be 429 840 euros. As with the normative approach, the optimal reserve pattern is also the most expensive one. But the difference in the sum of the payments necessary for the reserve obtained with a simple uniform payment without any shape considerations, and the environmentally optimal reserve obtained through the degressive payments scheme, is only 18 per cent, while is was more than 30 per cent within the normative approach. Even more interestingly, when the above discussed contract schemes are applied the sum of total payments necessary to obtain the second best reserve pattern – the one corresponding to a minimum of 10 per cent of each farm enrolled – is only by 3 per cent higher than the sum of the uniform payments applied without any farm-level participation restrictions. The difference was for the same reserve patterns 29 per cent within the normative approach. This means that also the way of implementation of a given reserve is to be considered when weighting the costs against the environmental benefits. Depending on the contract structure applied, the difference in costs can be considerably different for the same change in the environmental outcome.

5 Conclusion

A mathematical programming model has been developed to analyse the optimal reserve design and implementation for the little bustard conservation in *Plaine de Niort*. Simple in terms of the zone representation – 18 farms regularly distributed on a square of 2 700 hectares, but detailed in the farming systems description, and spatially explicit, OUTOPIE, connected to an efficient spatial pattern index – Ripley L-function, showed that it is able to give valuable insight into the conservation economics.

It was illustrated that the model can be applied both in a normative way as well as in a positive way. Within the normative approach, the major findings relate to the trade-offs between the reserve quality and its cost. It was found that the environmentally optimal reserve, which is randomly dispersed across the zone, is the most costly one because it requires equal participation of all, "low-cost" as well as "high-cost", farmers. Allowing higher concentration of the reserve on the "low-cost" mixed dairy farms enables to decrease the cost of the reserve but the spatial pattern of the reserve deteriorates. Depending on how the concentration of the reserve within a farm is restricted, the pattern and cost of the reserve change. A better reserve pattern for lower cost can be obtained if each farm is required to enrol at least a small area into the reserve and if we do not set an upper limit to the participation of the "low-cost" farms, than in the situation when an upper limit is set for all farms but some of them do not have to enroll any land at all.

Within the positive approach, it was illustrated that the various reserve patterns generated within the normative approach can be obtained through relatively simple uniform contract structures, which do not require the complete information about and negotiation with the individual farms. The most effective contract structure, which was able to encourage all the farms to enrol at least a small share of their farm into the reserve, is a set of two payments where one of them is guaranteed up to a certain share of the farm and the second, much lower, remunerates all the land enrolled above this limit. In terms of budgetary expenditure, this option costs nearly the same as a simple uniform payment scheme but can provide considerably better reserve patterns.

Finally, the simultaneous application of both the normative and the positive approaches enables to evaluate the cost-efficiency of the proposed contract schemes. In the presented scenarios, we have seen that the sum of the payments necessary to obtain a given reserve within the positive approach was always by at least 65 per cent higher than the actual cost of the same reserve calculated within the normative approach. This is because in the contract schemes we tested, the payment levels were not differentiated between "low-cost" and "high-cost" farmers, thus the "low-cost" farmers were overcompensated.

Although, or because, the model seems to be able to advice the conservation reserve design both in terms of its location and implementation, further research is desirable. We see two prominent directions which should be explored: First, new scenarios concerning the distribution of the farms across the zone should be investigated, so that the robustness of the results in terms of the reserve size and shape resulting from different contract schemes could be tested with respect to this parameter and the conclusions generalised. Second, a simple spatial pattern index able to account for the reserve characteristics in a coherent way should be incorporated into the model so that not only the desired reserve size but also its pattern can be controlled explicitly through a constraint or even through the objective function. This second feature would further increase the domain of applicability of the presented approach.

References

Agabriel, J., Champiaux, P. and Espinasse, C. (1999). *INRAtion-Pre´vAlim 2.7: logiciel de rationnement des ruminants*. Dijon: INRAtion–CNERTA diffusion.

Besag, J. (1977). Contribution to the discussion of Dr Ripley’s paper. *J. R. Stat. Soc.* B 39 : 193-195.

Bretagnolle, V. (2004). Prairies et cultures fourragères : Quels enjeux pour les oiseaux dans les milieux céréaliers intensifs ? Journées AFPF Biodiversité des Prairies, France.

Chamberlain, D.E., Fuller, R.J., Bunce, R.G.H., Duckworth, J.C. and Shrubb, M. (2000). Changes in the abundance of farmland birds in relation to in the timing of agricultural intensification in England and Wales, *Journal of Applied Ecology* **37**: 771–788.

Clark, P.J. and Evans, F.C. (1954). Distance to nearest neighbour as a measure of spatial relationship in populations. *Ecology* 35:23-30.

Donald, P. F., Green, R. E. and Heath, M.F. (2001). Agricultural intensification and the collapse of Europe’s farmland bird populations. Proc. *R. Soc. Lond. B* nº 268: 25-29.

Diggle, P.J. (1983). *Statistical Analysis of Spatial Point Patterns*. Academic Press, London.

Ekman, S. (2005). Cost-effective nitrogen leaching reduction as influenced by linkages between farm level decisions. *Agricultural Economics* 32: 297-309.

Falconer, K. and Hodge, I. (2001). Pesticide taxation and multi-objective policy-making: farm modelling to evaluate profit/environment trade-offs. *Ecological Economics* 36: 263-279.

Getis, A. and Franklin, J. (1987). Second-order neighbourhood analysis of mapped point patterns. *Ecology* 68: 473-477.

Gregory, R.D., Van Strien, A., Vorisek, P., Meyling, A.W.G., Noble, D.G., Foppen, R.P.B., Gibbons, D.W. (2005). Developing indicators for European birds. *Phil. Trans. R. Soc. B.* 360: 269-288.

Haase, P. (1995). Spatial Pattern analysis in ecology based on Ripley’s K-function: Introduction and methods of edge correction. *Journal of Vegetation Science* 6: 575-582.

Hassoul, N. (2005). *Etablissement d’une typologie spatialisée des exploitations agricoles de la Plaine de Niort Sud à des fins environnementales*. Master thesis directed by Havet, A. and Martin, P., UMR INRA-INA P-G SAD-APT. 33 p.

Inchausti, P. and Bretagnolle, V. (2005). Predicting short-term extinction risk for the declining Little Bustard (Tetrax tetrax) in agricultural habitats. *Biological conservation* 122: 375-384.

Jarrige, R. (1988). *Alimentation des bovins, ovins et caprins*. INRA, France.

Julliard, R., Jiguet, T. F. and Couvet, D., (2004). Common birds facing global changes: what makes a species at risk ? *Global Change Biology* 10: 148-154.

O’Connor, R.J. and Shrubb, M. (1986). *Farming and birds*. Cambridge University Press, Cambridge.

Potts, D. (1997). Cereal farming, pesticides and grey partridges, Farming and Birds in Europe. *The common agricultural policy and its implications for bird conservation*, Pain D.J. and Pienkowski M.W. eds, Academic Press, London, 150-177.

van Wenum, J.H., Wossink, G.A.A. and Renkema, J.A. (2004). Location-specific modeling for

optimizing wildlife management on crop farms. *Ecological Economics* 48: 395-407.
Veysset, P., Lherm, M. and Bébin, D. (2005). Adaptation to Agenda 2000 (CAP reform) and optimisation of the farming system of French suckler cow farms in the Charolais area : a model-based study. *Agricultural Systems* 83: 179-202.
Ripley, B.D. (1977). Modelling Spatial Patterns. *Journal of the Royal Statistical Society. Series B (Methodological)* 39: 172-212.
Williams, J.C., ReVelle, C.S., Levin, S.A. (2005). Spatial attributes and reserve design models: A review. *Environmental Modelling and Assessment* 10: 163-181.
Wossink, G.A.A, de Koeijer, T.J. and Renkema, J.A. (1992). Environmental-economic policy assessment: a farm economic approach. *Agricultural Systems* 39: 421-438.
Wossink, A., van Wenum, J., Jurgens, C., de Snoo, G. (1999). Co-ordinating economic, behavioural and spatial aspectsof wildlife preservation in agriculture. *European Review of Agricultural Economics* 26: 443-460.