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Methods

Farming system modelling for agri-environmental policy design: The case of a spatially non-aggregated allocation of conservation measures

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ABSTRACT

This paper addresses the issue of designing policies for habitat conservation on agricultural land. The case under study requires a non-aggregated spatial distribution of the fields to be enrolled in an agri-environmental programme. A spatially explicit mathematical programming farm-based model, which accounts for three spatial levels (field, farm and landscape), is coupled with a relevant spatial pattern index (the Ripley L-function) to analyse the design and implementation of an agri-environmental programme aimed to preserve the *Tetrax tetrax* in the *Plaine de Niort*, France. The model is run using a stylised map with heterogeneous soil types and both crop growing and mixed dairy farms. Results show that valuable insights into agri-environmental programme design are gained through a detailed representation of farming system management. The suitable, non-aggregated spatial pattern for *T. tetrax* conservation is more costly than less-suitable, more aggregated patterns, because it tends to require equal participation of all farms. The policy simulations reveal that the various spatial patterns can be obtained through relatively simple uniform contract structures. An effective contract structure entails a set of two degressive payments which encourages all farms to enrol at least a small share of their land in the program.

1. Introduction

Over the last fifty years, in western European countries, dramatic changes have taken place in the farming landscape. This is mainly due to mechanisation, the intensification of farming techniques and farm specialization as well as increases in the use of chemicals and the size of agricultural fields. While the productivity of European agriculture has considerably increased over this period, the range of biodiversity has suffered (Pain and Dixon, 1997; Söderström and Pärt, 2000; Chamberlain et al., 2000; Donald et al., 2001). For example, common farmland birds of Europe have declined by 25% over the last two decades (Gregory et al., 2005).

In the early 1990s, in order to minimize the negative environmental impacts of agriculture intensification, agri-environmental policies were integrated into the Common Agricultural Policy. The Natura 2000 programme was initiated to protect the most seriously threatened habitats, including those in farmland areas. In the latter case, specific agri-environmental regulations and incentives have been implemented by Member States to promote farming practices that ensure biodiversity.

This is the case in the *Plaine de Niort* (Poitou-Charente), France, where a Natura 2000 site has been designated to halt the decline of *Tetrax tetrax* (*Little Bustard*), an Annex 1 species of the EU Birds Directive (79/409/EEC). The Poitou-Charente region, located in western France, harbours the sole remaining Little Bustard migratory population in farmland areas. This population has undergone one of the steepest declines ever documented for a contemporary bird species in Europe, i.e., from a high of 7800 males in 1978 to a low of 300 in 2008, attributed to land use changes and the intensification of agriculture.[2] Over the next 30 years, the Little Bustard has a 45% chance of undergoing extinction (Inchausti and Bretagnolle, 2005). These birds mate and breed in an arable landscape that is composed of alfalfa, grasslands, and annual crop fields. (Salamolard and Moreau, 1999; Wolff et al., 2002). Their conservation in the Natura 2000 site requires a non-aggregated distribution of extensively managed grasslands.

In this paper, we address the issue of designing a Little Bustard-friendly (LBF) agri-environmental programme (AEP). This type of programme not only implies devising the incentives needed to encourage farmers to adopt LBF conservation measures. It must also take into account the important role of the spatial allocation of the fields to be enrolled in any undertaken conservation programme.

Our investigation into this is innovative in two ways. Firstly, we present a spatially explicit mathematical programming model which

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[2] The estimated French population size was 8500 males in 1978–1979, falling to 1300 males in 2000 (Jolivet and Bretagnolle, 2002).

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consistently links several detailed farm-level models with the field and landscape levels. It is thereby able to endogenously assess the location and cost of fields to be enrolled in the programme. Secondly, this model is associated with a relevant spatial pattern indicator (the Ripley L function) to address the as yet untreated issue of a non-aggregated distribution of fields enrolled for conservation and to discuss the design of an AEP aimed at providing such a spatial pattern.

The presented approach is related to the vast literature investigating, on the one hand, reserve site selection and reserve design, and, on the other hand, agri-environmental and conservation policy design. Reserve site selection has been largely studied in the field of conservation biology (e.g., Kirkpatrick, 1983; Vane-Wright et al., 1991). It generally involves minimizing the number of sites or total reserve area necessary to protect a given set of species. Or, inversely, studies aim to maximize the number of species protected for a given number of sites or total reserve area. More recently, economists have introduced land costs and budgetary issues into the analysis to address the issue of cost-effectiveness (i.e., to minimize costs for a given conservation effort) (Ando et al. (1998), Polasky et al. (2001), Naidoo et al. (2006)). In contrast to reserve site selection, reserve design models account for the spatial aspects of the reserve, comprehensively reviewed by Williams et al., 2005. Studies devoted to both approaches define “reserve” as undisturbed nature. However, a conservation strategy based on nature reserves or national parks is neither appropriate nor achievable in most of the farmed European landscapes. Hence, “working land” as well as alternative land uses and management options must be integrated into the analysis (e.g., Polasky et al., 2005, 2008; Nalle et al., 2004). This has been done for agricultural land by authors like Wossink et al. (1999) or van Wenum et al. (2004).

While the above-mentioned studies focused more on the question of where the “reserve” should be set up, another important issue is how to implement these desirable “reserve” spatial patterns. Optimal reserve design studies usually assume that the social planner has perfect knowledge of all costs and selects sites based on their opportunity cost, which he compensates for. In reality, conservation policies are often incentive-based because governmental agencies enforcing them only have imperfect information on private costs, or, even if the Government sometimes has the necessary information, it cannot use it for political reasons (Chambers, 1992).Recent work has been carried out on a regional basis which has explicitly taken into account spatial landscape patterns in the effects of incentives-based policies for conservation on agricultural land (e.g., Drechsler et al., 2007, 2010; Hartig and Drechsler, 2009; Johst et al., 2002; Lewis and Plantinga, 2007; Lewis et al., 2009; Wätzold and Drechsler, 2005; Wätzold et al., 2008). However, these studies either do not account for the farm level, or they oversimplify farmers' behaviour, while they all consider exogenous land-use opportunity costs for individual plots. The latter assumption overlooks the fact that in a farming system the opportunity cost of a change in land use or land management on one field does not exist independently of other decisions due to, for instance, rotational effects or cattle feeding requirements. As pointed out by Hynes et al. (2008), it is the farmers who ultimately take the decision and therefore determine the effectiveness and efficiency of an agri-environmental programme. Based on the representation of the technical and economic behaviour of farms, mathematical programming farm-level models have largely been used by agricultural economists to assess the efficiency of environmental policies (e.g. Falconer and Hodge, 2001; van Wenum et al., 2004; Ekman, 2005; or Havlik et al., 2005; Wossink et al., 1992). However, this modelling framework has rarely been used to address the issue of the spatial location of production choices.

Our approach departs from the existing literature in that we have developed a spatially explicit and detailed farm-based optimization model in which technical and administrative constraints influencing land management choices, in addition to farmers' profit-maximizing behaviour, are accounted for at the farm level. This model is thus able to determine endogenously farmers' conservation compliance costs, and it can be used both for the analysis of the spatial allocation of conservation measures and for AEP design.

Our approach is also different from the existing literature because we account for a non-aggregated spatial distribution of fields to be enrolled in a conservation effort. As Williams et al. (2005) have pointed out, the spatial configuration of reserves matters if we are to ensure the long-term persistence of species. The choice of the reserve spatial attribute to retain, such as connectivity or shape, depends on the species and conservation objectives. While contiguity and connectivity have often been studied (e.g., Wossink et al., 1999; Nalle et al., 2004; Parkhurst and Shogren, 2008), to the best of our knowledge, in the field of spatially explicit modelling of biodiversity conservation in agricultural land, this study is the first attempt to account for a non-aggregated spatial distribution of land.

The paper is structured as follows. The methodological aspects involving the modelling approach, the conservation problem, and the method used to characterize the mosaic landscape are covered in Section 2. The area under study and the applied model are described in Section 3. In Section 4, we explore where the extensively managed grasslands should be located so that the cost, in terms of foregone farm income, is the lowest, accounting for soil heterogeneity. We also investigate the trade-off between a deviation from the desired non-aggregated pattern and the corresponding cost change. We then examine different payment schemes likely to produce these landscape patterns and evaluate them in terms of landscape pattern quality and budgetary expenditure. In Section 5, we conclude, discuss the adopted approach and our findings, and make suggestions for further developments.

2. Methodology

2.1. Modelling Approach

OUTOPIE (OUTil pour l'Optimisation des PrairIes dans l'Espace) is a mixed integer linear programming model which accounts for three spatial levels: field, farm and landscape/region. 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, irrigation equipment (or not), and the farm to which they belong. The farm is the level at which decisions concerning land allocation are made, taking into account regulation and policy constraints (e.g., milk quotas and obligatory set aside), as well as technical constraints such as feed requirements. Finally, spatial relationships between fields relevant for the Little Bustard are accounted for at the regional level. From this section on, we will refer to alfalfa and temporary or permanent grassland, enrolled in a Little Bustard Friendly (LBF) agri-environmental programme, indifferently as LBF managed grasslands, land for Little Bustard conservation, or land enrolled in the Little Bustard conservation programme.

The model, in general, maximizes the sum of all farms' gross margins—including payments and costs due to the participation in an LBF agri-environmental programme—subject to field, farm and landscape level constraints. This is represented in optimisation programme (1), where $X_{f,i,c}$ is the level of the different farm activities for farm f, on field/plot i enrolled (or not) in one of the LBF managed grassland types c, Π_f is the farm gross margin from agricultural activities, cp_c is the compensation payment for a LBF managed grassland type c, vtc_c is a variable transaction cost per hectare of enrolled land, ftc is a fixed private transaction cost per farm, P_f is a binary variable equal to 1 if the farm participates in the agri-environmental programme (AEP), and ptc is a fixed public transaction cost per farm participating in the AEP. We considered both private and public transaction costs as they play an important role in both the cost of agri-environmental policies and the farmers' decision to take up the agri-environmental programme (Falconer et al., 2001).

$$\mathrm{Max}\sum_f\left[\Pi_f\left(X_{f,i,c}\right)+\sum_{c,i}(cp_c-vtc_c)\cdot X_{f,i,c}-ftc\cdot P_f\right]-ptc\cdot\sum_f P_f \qquad (1)$$

s.t. $Field(X_{f,i,c})$, $Farm(X_{f,i,c})$, $Landscape(X_{f,i,c})$

The model can be used either to investigate where the LBF managed grassland fields should be located or to test agri-environmental policies. In the first case, a constraint is introduced that imposes—at the landscape level—the minimum area CA to be enrolled in the Little Bustard conservation programme and its required spatial distribution corresponding to a value of a spatial indicator SI (see Eqs. (2) and (3)). Compensation payments cp_c are set to zero and the public transaction cost ptc per farm is positive. The cost of the land required to ensure LB conservation is calculated as the difference between the sum of gross margins (including private transaction costs) without and with constraints (2) and (3), plus the public transaction cost.

$$\sum_{f,i,c}X_{f,i,c}\geq CA \qquad (2)$$

$$SI\left(X_{f,i,c}\right)\geq SI \qquad (3)$$

In the second case, agri-environmental payments cp_c that compensate farmers for the fields enrolled in the LBF AEP are strictly positive, and their impact on the size and location of the contracted fields is evaluated through Eqs. (2′) and (3′). The latter two are simply constraints (2) and (3) transformed into accounting equations by replacing the exogenous conservation requirements, CA and SI, by equivalent accounting variables *ConservedArea* and *SpatialIndicator*. The public transaction cost ptc is set to zero in the objective function as it does not affect farmers' decision to take up the AEP. Instead, it is used to compute the total cost of the conservation programme post-optimisation, which—in addition to the cost of land under conservation mentioned above—also accounts for the informational rent received by farmers that depends on the way the compensation payment is awarded.[3]

$$\sum_{f,i,c}X_{f,i,c}=ConservedArea \qquad (2')$$

$$SI\left(X_{f,i,c}\right)=SpatialIndicator \qquad (3')$$

Individual cropping and breeding activities, agri-environmental measures, transaction costs, and data sources used in the model are further detailed in Section 3.

2.2. Spatial Pattern Analysis

The decline in Little Bustard populations has been attributed to the decrease in extensive grasslands in farmland habitat (Bretagnolle, 2004). In fact, this decrease affects the insect abundance on which the bird depends. Adult Little Bustards mainly feed on insects during the summer and bustard chicks feed exclusively on grasshoppers (Jiguet, 2002). In order to maximise grasshopper distribution and abundance in agricultural habitat, extensive temporary grasslands should be distributed throughout the landscape in rather small patches, especially if the total area of grassland is limited, such that the dynamics of the metapopulation ensures the persistence of insect populations (Hanski, 1999; Appelt and Poethke, 1997). In addition, Little Bustards show a lekking mating system with an extreme separation of sexes in their role to achieve breeding (males are only involved in copulation for breeding, Jiguet et al. (2000)). For mating to occur, females must be readily able to detect males who therefore display themselves on low cover, for instance sunflower, which, in spring, is in an early stage of growth, or ploughed land. Females, however, prefer alfalfa, grasslands and fallow, where they find both shelter and food (Salamolard and Moreau (1999), Jiguet et al. (2002), Wolff et al. (2001, 2002)). The most suitable landscape spatial pattern for Little Bustard conservation therefore requires the following two characteristics: at least 15% of the land should be covered by extensively managed grassland patches (3 ha being the ideal field size); and the patches should be located in function of a non-aggregated pattern. In the given case, within any radius between 100 and 1000 m, the fields should be randomly distributed, as opposed for example to an aggregated or an over-dispersed pattern. (Bretagnolle, 2004; Bretagnolle et al., in review) (See Fig. 1a for an example of random vs. aggregated distribution).

Given these two characteristics, we need to measure not only the total area of fields enrolled in the conservation programme but also their spatial pattern. The former being straightforward, we will focus here on the measurement of the spatial pattern with the Ripley K and L functions.

The Ripley K and L functions (Ripley, 1977, 1981) are part of spatial point pattern analysis methods. These functions combine 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 stationary constructions (Haase, 1995). The Ripley K and L functions are the most appropriate indices for the present study.

Let A be the area of the zone under study, N the number of observed LBF-managed grassland plots, and λ the density ($\lambda=N/A$). $\lambda*K(r)$ can be interpreted as the expected number of further LBF managed grassland plots within a radius r of any arbitrary plot. If the fields dedicated to conservation are randomly located, following a Poisson distribution, then the expected value of $K(r)$ equals πr^2.$\hat{K}(r)$ is an unbiased estimator of $K(r)$ calculated as follows:

$$\hat{K}(r)=\frac{1}{\lambda N}\sum_i\sum_{j\neq i}\left(w_{ir}*I_r\left(d_{i,j}\right)\right) \qquad (4)$$

where $d_{i,j}$ is the distance between two LBF managed grassland plots, I_r a binary variable equal to 1 if $d_{i,j}\leq r$ or to 0 otherwise, and w_{ir} an edge-effect-correction weighting factor. Like many others, we apply the normalised form of $\hat{K}(r)$, i.e., $\hat{L}(r)$ (Besag, 1977; Ripley, 1981), which has an expected value of zero for a random Poisson distribution (see Eq. (5)).

$$\hat{L}(r)=\sqrt{\frac{\hat{K}(r)}{\pi}}-r \qquad (5)$$

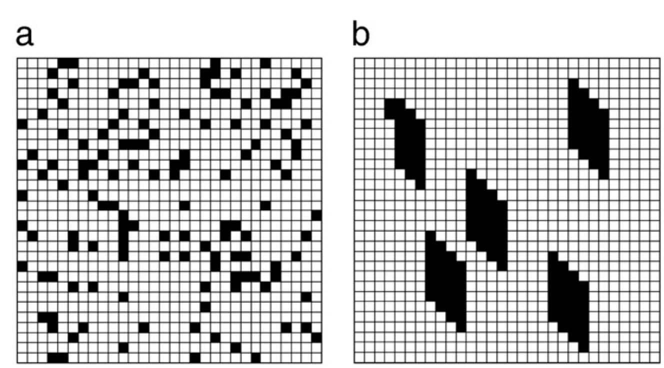

Fig. 1. Examples of the spatial distribution of 135 conservation plots on a 900-plot grid: a) random and b) aggregated.

[3] E.g. uniform payment per hectare needs to compensate for even the most expensive last plot enrolled in the AEP; there is therefore a rent, arising on all the cheaper fields, which is equal to the difference between the compensation payment and the actual conservation cost (the conservation cost is equal to the profit foregone plus the private transaction costs).

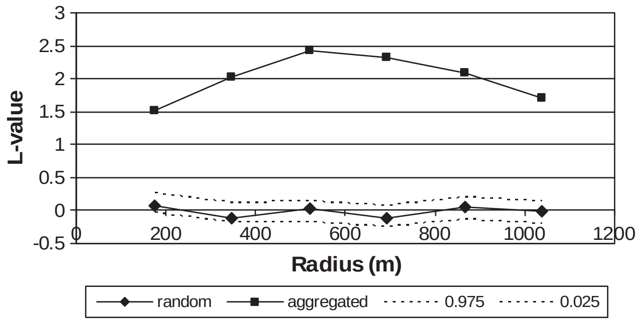

Fig. 2. Ripley L function for an aggregated and a random spatial distribution of the conservation plots, c.f. Fig. 1.

Once the $\hat{L}$ function is assessed for the spatial distribution of the plots under conservation in a scenario, it has to be tested against the null hypothesis of Complete Spatial Randomness (Diggle, 1983). We used the Monte Carlo method to create a 95% confidence envelope.[4]

Results can be interpreted as follows (c.f. Fig. 1 for two spatial distributions of the fields under conservation and Fig. 2 for the associated values of $\hat{L}$): a) if $\hat{L}(r)$ remains within the confidence envelope (dotted lines in Fig. 2) then the spatial pattern of the LBF managed grassland fields is significantly (Poisson) random; b) if the deviation from zero is significantly positive, i.e., $\hat{L}(r)$ is above the upper limit of the confidence envelope, then the spatial pattern is clustered or aggregated.

The scale of interest and the intervals between radii depend on the species and the issue which is being addressed. In our case, the analysis of the Ripley $\hat{L}(r)$ function should be limited to the Little Bustard relevant radii ranging from 100 to 1000 m, and to intervals equal to the distance between two fields.

3. Case Study

3.1. Stylising the Area under Study

Our research is focused on a core area of the Poitou-Charente region: a Natura 2000 Special Protection Area located in the *Plaine de Niort* (FR5412007), in the French département des Deux-Sèvres. This area was traditionally dedicated to mixed farming but has undergone a rapid specialisation in crop production: more specifically, the area in meadows and pastures dropped by 60% between 1988 and 2000 to currently represent only 13% of the local agricultural area. It is being replaced by annual crops (mainly wheat, maize, and rapeseed). Between 1988 and 2000, the number of mixed farms dropped by 40% to currently represent only 26% of the agricultural area of les Deux-Sèvres. The entire Natura 2000 site includes about 20,000 ha and is composed of circa 7000 fields.

We have chosen to concentrate on a stylised area restricted to 2700 ha divided into 900 fields, 3 ha each (cf. Fig. 3). The size and characteristics of this stylized area are consistent with local ecological and economic considerations :i) a sustainable Little Bustard population of about 20–25 individuals (i.e., 3–4 leks; Inchausti and Bretagnolle, 2005) lives on approximately 3–5000 ha, ii) a 3-hectare grassland patch size is required for Bustard conservation, and it is close to the current average field size within this Natura 2000 site; iii) different soil qualities are represented according to the observed ratio and layout; iv) the two main farming systems (crop and mixed-dairy farms) are accounted for. We decided not to account for differences in farm size or farm plot

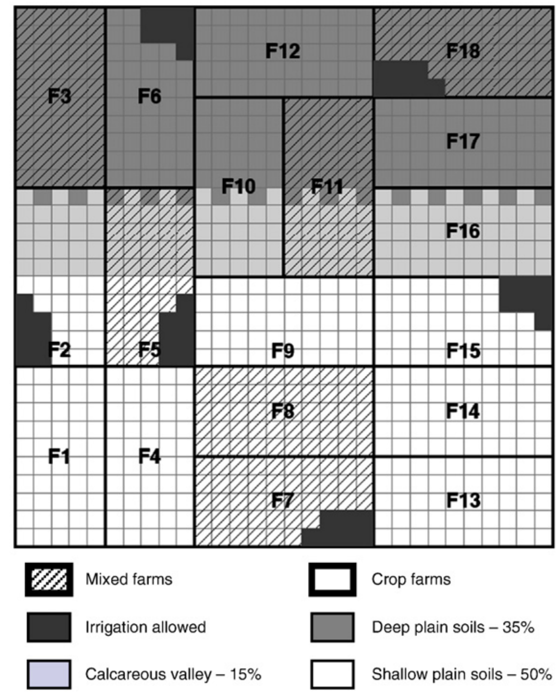

Fig. 3. Model representation of the area under study.

distribution. We therefore took all farms to be 150 ha in size, with aggregated fields, allowing us to better assess the impact of soil heterogeneity between farms on their participation in the AEP and on the location of enrolled fields.

3.2. Modelling Crop and Mixed Dairy Farms

On a crop farm, the basic decision variable is the share of each field allocated to a specific crop rotation. The model accounts for the major crops (wheat, winter barley, sunflower, rapeseed, maize, and sorghum), for permanent as well as temporary grasslands, including alfalfa, and for set aside land. Crops are divided into different cropping activities depending on i) the preceding crop, ii) crop use, iii) the duration of perennial crops (e.g., alfalfa cultivated for 3 or 4 years) and iv) the cropping technique (rain-fed, irrigated or LBF). These crops are combined into 52 crop rotations including new rotations devised to let farmers adapt their production system to the agri-environmental programme. Crop rotations and yields on each of the soil types were provided by agronomists and local experts.[5]

Mixed 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 subject to constraints such as milk quotas and cattle demography. The link between the herd size and milk production is achieved through feed rations. The dairy-cattle breeding module[6] accounts for 18 animal types

[4] More details on the computation and interpretation of the Ripley K and L function are provided in the Appendix.

[5] The information has been collected inside an interdisciplinary research project, coordinated by G.Lemaire, INRA-Lusignan. Information on alfalfa and grassland management was provided by M.Laurent UEFE, INRA-Lusignan. For the other crops, yields were evaluated for each type of soil, taking into account the preceding crop effect, using the PERSYST model developed by L. Guichard, UMR Agronomie INRA-Grignon.

[6] The dairy cattle breeding module is derived from the Opt'INRA model, initially developed for suckler cow breeding (Veysset et al., 2005) and adapted to dairy cows in Poitou-Charente by LEE INRA Clermont-Theix. Feed rations are based on local practices or composed with the use of INRATion software (Agabriel et al., 1999).

(differentiated by age, state and feed requirements), 7 forage types (grazed grass, grass hay, grass silage, alfalfa hay, maize silage, cereals, and cattle-cake) and 80 feed rations.

The policy framework of our investigation is based on the 2003 CAP reform, with a 10% obligatory set aside rate. Single payments and decoupled premium for animals were calculated with local references. Crop prices and production costs are based on data from the 2005 FADN, the regional Centre d'Economie Rurale and experts. Production costs and prices for milk and animals were provided by Institut de l'Elevage, Poitou-Charente, for 2005.

For cash crop farms, the production of alfalfa is a new cropping activity, encouraged by the agri-environmental payments and for which farmers could possibly have an outlet by selling it to the local dehydration firm involved in fodder production. In order to avoid the overestimation of compensation payments, we have therefore included the possibility for all farms in the model (crop growing and mixed-dairy farms) to sell alfalfa at the market price (see Table 1).

3.3. Modelling the LBF Agri-environmental Schemes

In the studied area, an agri-environmental programme is currently implemented to encourage farmers to maintain and expand grasslands and to manage them in a Little Bustard-friendly way. This LBF management is characterized by restrictions on livestock density, fertilisation, pesticides, and mowing dates. In the model we consider as land under conservation all the land use types eligible for the Little Bustard AEP, i.e., permanent grasslands, temporary grasslands and alfalfa fields. The current LBF AEP requirements and compensation payments are detailed in Table 1.

The aim to analyse precisely the spatial pattern of the fields enrolled in the conservation programme requires two adjustments of the model structure presented so far. First, the decision variables which express the share of each plot enrolled in the conservation programme are to be binary. Second, in order to observe the location over time of fields to conserve, we add an index to each LBF conservation relevant crop rotation, indicating at which stage the rotation starts. To keep things simple, we did not introduce a discount rate to compute the gross margins of LBF crop rotations.

The private and public transaction costs related to the agri-environmental programme have been accounted for (see Table 1). Private transaction costs are divided into fixed costs per farm corresponding to the time spent to gather information, to apply for AEP and for monitoring; and into variable costs per hectare enrolled, corresponding to the time spent for reporting to the administration and auditing. These values are taken from Peerlings and Polman (2004, 2008), and are in accordance with Falconer (2000). Public transaction costs correspond to the time spent to advertise for the AEP, to negotiate, contract and monitor (Falconer et al., 2001).[7]

Table 1
Characteristics of the agri-environmental programme to ensure Little Bustard conservation.

Current AEP payments for LBF management	Permanent grassland 91.5€/ha, Temporary grassland 110€/ha, Alfalfa 450€/ha
LBF management requirement	
• Permanent and temporary grasslands	Nitrogen limit :60 kg per ha Animal density limit :1.4 livestock units per ha Mowing dates: After May first
• Alfalfa	Mowing forbidden between May 15th and July 31st Pesticide spraying forbidden between 1st April and 15th November Irrigation forbidden
AEP fixed private transaction costs	175 €/farm for the 5-year contract
AEP variable private transaction costs	4% of the AEP compensation payment
AEP public transaction costs	724€/farm taking up the AEP for the 5-year contract

3.4. Validating the Model

To validate our model we first compared farm results to the observed 2005 data—the year for which we have farm type data. We then compared the stylised area land use to the observed 2003 situation—the year for which we have the Natura 2000 site land use. The validation scenario entails maximising the gross margin of each farm, given the current LBF agri-environmental payments for enrolled fields.

We compared our crop farms' simulated land use to data for farms growing cereal, oilseed and protein crops[8] provided by the French agricultural bureau of statistics (Enquête Structure 2005[9]) at the département level, which is the smallest administrative level for which data are available. Cereal crops represent 65.7% of land in the validation scenario and 58% in the observed situation. Oilseed and protein crops, taken together, represent 24.3% and 35% respectively.

We validated the behaviour of mixed dairy farms by ensuring that our characterisation was consistent with the characteristics of the mixed dairy farm types described by the French Breeding Institute (Institut de l'Elevage) and reflecting the different local livestock orientations.[10] Farms were discriminated according to 4 criteria: the share of cash crops in the utilised agricultural area, the share of maize in the fodder crops area, the area in grassland per livestock unit, and the share of grazing in the feed ration. In the model, five farms out of six behave as “forage stocking-based” farms, for which feed rations mostly depend on maize silage and dried fodder, representing, over a year's time, at least 75% of them. Maize represents at least 34% of the total area dedicated to fodder crops. One farm behaves as a “pasture-based” farm, which relies mostly on grazing (grazed grass is the exclusive feedstock for at least 8 weeks per year, and fodder maize represents less than 23% of the total fodder crop acreage).

Finally, we compared our stylised area simulated land use to the observed one involving the Natura 2000 site in 2003.[11] Table 2 shows that they are quite similar. The LBF managed grassland fields, obtained in the case of the validation scenario, covers 5% of the stylised area (Fig. 4). This result is consistent with the share of Natura 2000 acreage actually contracted under the LBF AEP in Poitou-Charente (7500 ha of the 142 655 ha, i.e., 5.2%[12]). In addition, only mixed dairy farms take up to the scheme, enrolling on average 15% of their area in the conservation programme. These results correspond well to the situation observed in the field, where only very few crop farms participate in the existing AEP, and the average share of the mixed farms enrolled in the programme does not exceed 20% of their land (between 12% and 20% in our case). It is noteworthy that in the validation scenario using the actual agri-environmental payments, the area under conservation programme has too few hectares and an

[7] Information on time spent administrating the contracts was provided by the Direction Départementale de l'Agriculture (Departmental Agricultural Services) of the département des Deux-Sèvres, the local public service in charge of agri-environmental programmes. It is composed of half a day per year (times 5 in our case) for the control, plus 1.5 days for contract administration and 1 day for information and negotiation for the entire 5-year period. We therefore took the cost to be 1 week of work for a civil servant in charge of the administration of contracts. Public transaction costs will vary depending on the implementation, i.e., regulation, uniform or differentiated incentive payments. Unfortunately, we did not have data to account for these differences.

[8] I.e., Type of Farming 13, in accordance with FADN classification: http://ec.europa.eu/agriculture/rica/detailtf_en.cfm.

[9] http://agreste.maapar.lbn.fr/ReportFolders/ReportFolders.aspx, « STRU005 ».

[10] http://www.inst-elevage.asso.fr/html1/IMG/pdf_CR_080755002.pdf. It was not possible to use the French agricultural statistics at the département level, for mixed dairy farms were aggregated with other FADN “Types of Farming”.

[11] The 2003 land use is the only one available.

[12] http://www.outarde.lpo.fr/images/fich48847aea5d97e-PlaqOutarde.pdf.

Table 2
Actual land use of the Natura 2000 site in 2003 and simulated land use of the stylised zone for 2005.

Land use	Natura 2000 site (2003 data)	Stylised area (simulation for 2005)
Cereal crops (excl. Maize)	37%	48.6%
Oilseed crops	21%	22%
Maize (incl. Silage)	15%	12.2%
Grasslands	13%	8.1%
Protein crops	2%	
Set-aside	9%	90%
Other	3%	

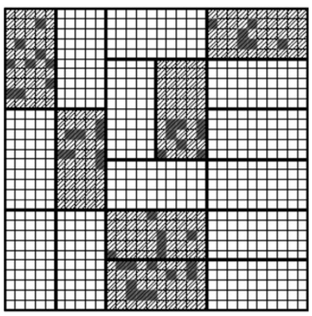

Fig. 4. LBF managed grassland fields location obtained within the validation scenario.

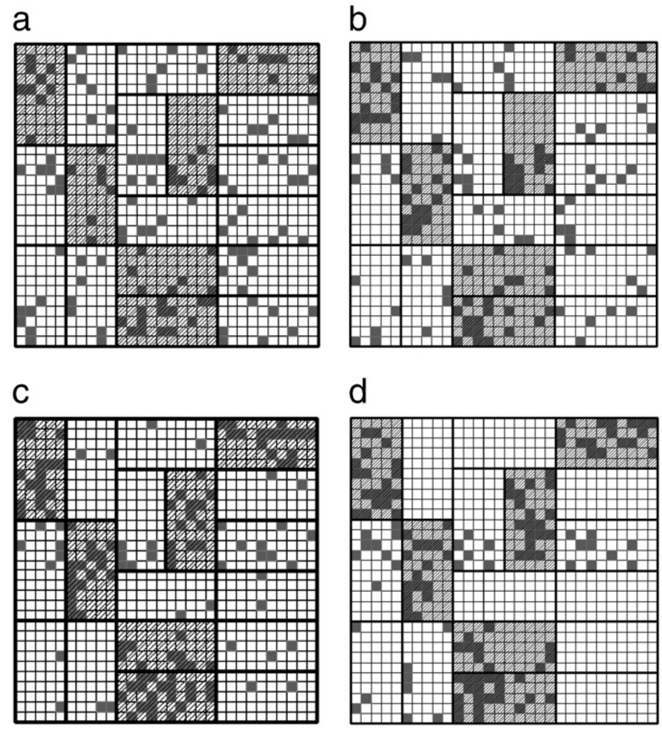

Fig. 5. Suitable spatial pattern for *Tetrax tetrax* conservation (a); and spatial pattern obtained when the minimum share of each farm to be enrolled in the conservation programme is set at: b) 10%, c) 5% and d) 0%.

overly-aggregated spatial pattern in comparison to Little Bustard requirements.

4. Simulations and Results

4.1. Investigation into the Trade-offs between the LBF-managed Grassland Pattern and its Cost

Our first objective was to find the solution that minimizes the cost of a given conservation objective, which in our case requires that 15% of the area under study be covered with LBF managed grassland fields randomly distributed for any radius r ranging from 100 m to 1000 m. To that end, two additional constraints have to be introduced into the model: one for the total amount of area required and the other for its spatial pattern. We therefore imposed a minimum of 15% of LBF managed grassland in the stylised area. We did not however explicitly include the Ripley index L(r) in the model, since complex non-linearities, together with a high number of binary variables, do not make it possible to solve the problem within an optimization framework. As a consequence, we had to approximate the cost-minimizing effective spatial pattern by a proxy constraint, obliging all farms to dedicate 15% of their land to Little Bustard conservation, which still represents an effective solution from the environmental point of view (i.e., which meets the conservation requirements). We then investigated the trade-offs between the spatial pattern of land to conserve and its cost, the conserved area being equal, by relaxing this proxy constraint.

We found that in the case given here, the suitable spatial distribution for bird conservation can be obtained through a constraint requiring that all farms contribute equally to the conservation programme, each enrolling 15% of their land (scenario 1C). The generated landscape and the corresponding *L* function values are depicted in Fig. 5a and Fig. 6 respectively. They are put to work as a benchmark for the analysis to follow.[13]

The cost of the suitable spatial pattern for conservation—calculated as the difference between the total gross margins (including private transaction costs) obtained without and with size and shape requirements, plus the public administration costs—is 194 060€. This represents 7% of the total unconstrained gross margin. The cost for the total land required for conservation is then 479€/ha on average; however, this differs from farm to farm, depending on the farm type and soil quality. Mixed farms on shallow plain soils have the lowest average foregone profit: 81€/ha. They manage a part of their grassland according to LBF practices even in the absence of a conservation programme. The expansion of these management practices to a few additional hectares does not require major changes in the dairy herd size or structure: there is only a small decrease in the cropland area (around 8%) for a 23% increase in grassland and alfalfa area. Overall, that gives rise to a higher proportion of "grass" fodder and grazing in feed rations, substituting for maize silage, together with a slight decrease in purchases of concentrated feedstock. Crop

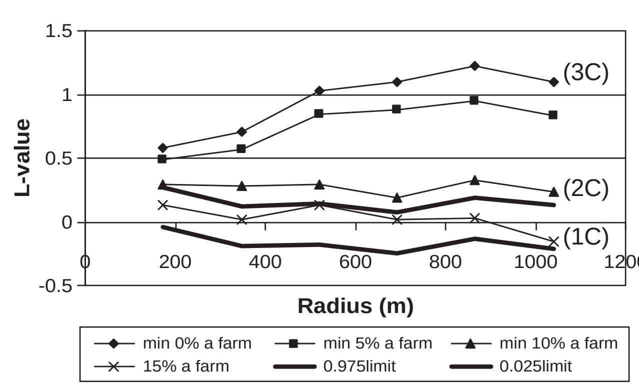

Fig. 6. L-function values for the suitable (random) spatial pattern for Tetrax tetrax conservation and for the spatial patterns obtained with different minimum shares of each farm to be enrolled in the conservation programme.

[13] More precisely, Figs. 5a and 6 represent the solution for the first year of the 11-year period. The spatial pattern of LBF managed fields will change within each farm over time. However, tests carried out for the other years show that the L-values for all of them are close to one another.

farms on very fertile deep plain soils have an average foregone profit higher than 780€/ha of LBF managed grassland. They substitute cash crops with alfalfa and temporary grassland, which makes them lose 13% of their gross margin even though they are allowed to sell their alfalfa. In general, the average foregone profit does not exceed 148€/ha of LBF managed grassland in the case of livestock farms, and it does not fall below 585€/ha in the case of crop farms.

If the farms that represent a "low-cost" for conservation were allowed to provide a larger part of the required land and the farms representing a "high-cost" for conservation could decrease their share, then the total area for the Little Bustard conservation would cost less. Let us now consider the option[14] to relax the spatial pattern constraint by setting the minimum share to be enrolled in the conservation programme by each farm below 15%. In this case, the rest of the land can be provided by the "low-cost" farms. Fig. 5b–c–d shows how the location of land for conservation changes when we oblige each farm to enrol at least 10% (scenario 2C) or 5% of its land, or when there is no minimum participation required (scenario 3C, i.e., minimum 0% per farm, Fig. 5d). Fig. 6 shows how the spatial pattern deteriorates (aggregates) as the minimum share to be enrolled by each farm decreases. The pattern of land for conservation associated with scenario 2C can be considered almost "suitable". The annual cost of the total land under conservation decreases to 169 696€, 154 445€, and 149 101€ if the minimum participation constraint is set to 10%, 5% and 0% of each farm, respectively.

Private transaction costs represent circa 5% of farmers' total conservation cost. They do not really impact farmers' participation in the AEP, as the fixed transaction cost per farm never exceeds 2% of the total conservation cost.

4.2. Policy Simulations

In this section, the model is used to test farmers' responses to various agri-environmental schemes and to set up contract schemes which would make it possible to reach or approach as nearly as possible, the suitable spatial pattern 1C, presented in Section 4.1.

Implementing the effective reference solution 1C supposes that we have complete information about each farm, and thus can go to each farmer and propose to him/her a contract which determines the area he/she should enrol, as well as the payment which would precisely compensate him/her for the cost of the LBF managed grasslands. However, the cost of gathering information on this precise compensation payment for each field and the negotiation with each farmer would probably make the implementation of the scenarios 1C and 2C too costly in the real-life situation. Therefore, agri-environmental schemes usually propose a uniform, non-differentiated across-farm payment, per hectare of LBF managed grassland to all farmers while letting farmers choose the area they wish to enrol.

Using the model, we calculated that a payment of 690€/ha would be necessary if all the farmers are to enrol 15% of the overall farmland in the LBF agri-environmental programme. This would therefore cost 280 941€[15] (scenario 3P). However, the resulting spatial pattern is highly aggregated and thus not acceptable (see Fig. 7). This scenario is equivalent to scenario 3C, where only the total area for conservation is constrained, at the level of the area under study.

The contract scheme able to ensure the "almost suitable" pattern for conservation, 2C, would require a slightly more complex structure. We found that both a payment of 810€/ha, for up to 10% of a farm area, and an additional payment of 450€/ha, above this limit, are necessary (scenario 2P). The cost of this programme, which leads to an "almost suitable" land pattern (see Fig. 7), is 282 056 €.

[14] We also tried to relax the "15% a farm" constraint by setting a maximum participation level above 15%. It did not perform better than the minimum participation constraint, neither in terms of pattern quality nor in terms of conservation cost.

[15] Compensation payments plus public administration costs.

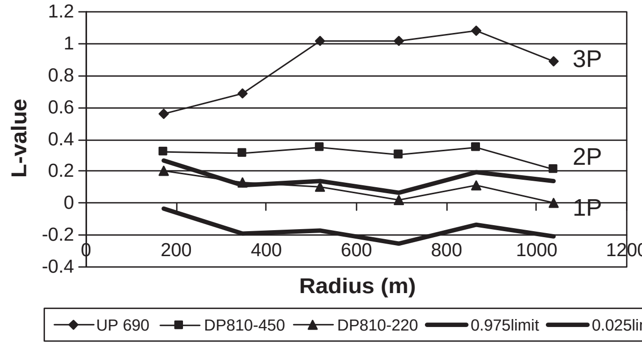

Fig. 7. L-function values for uniform (3P) and degressive (1P and 2P) payment schemes.

Finally, even the suitable reference pattern 1C can be obtained when paying both 810€/ha for up to 14% of each farm area and an additional 220€/ha over and above this limit (scenario 1P), for a programme costing 314 726€.

Public administrative costs are higher in scenarios 1P and 2P compared to scenario 3P, as more farms take up the AEP. However, they never exceed 1% of the total programme budget.

4.3. Comparison of Conservation Costs with the Budgetary Costs of Policies

The cost of the land to come under conservation measures (generated in Section 4.1) and the budgetary cost of the corresponding programmes (simulated in Section 4.2) are compared in Fig. 8. We can see that the latter is always at least 62% higher than the former; the reason being that agri-environmental payments are not differentiated between farmers and thus "low-cost" farms are overcompensated. The sum of total payments necessary to implement the "almost suitable" pattern obtained in 2P is only 0.14% higher than the sum of the uniform payments in 3P, whereas the difference in the conservation cost between the corresponding patterns 2C and 3C is 13.8%. This difference means that the way a conservation measure is implemented is also to be considered when weighing the costs against environmental benefits. Depending on the institutional arrangement (e.g., perfect discrimination versus single uniform contract), the difference in costs can be quite different for the same change in the environmental outcome.

If farmers did not have the possibility of selling their alfalfa fodder, the necessary compensation payments would be substantially higher; e.g., the uniform payment necessary to have 15% of the land enrolled in the AEP would rise from 690€ to 867€, i.e., by 25%. This is due to the fact that the average foregone profit for crop farms would rise by 43%, as they can neither use nor sell the alfalfa fodder. In addition, the total conservation cost in Section 4.1 would rise by 13% to 33%, depending

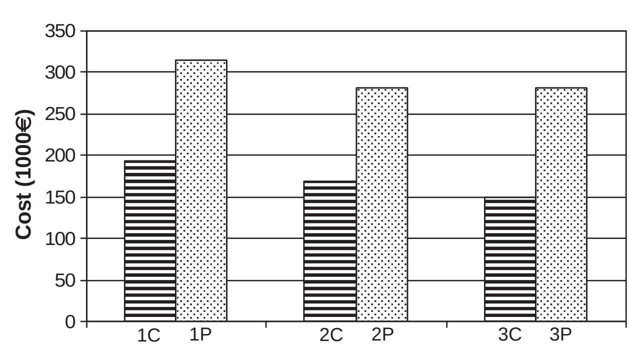

Fig. 8. Cost of the conservation measures (scenarios 1C, 2C, and 3C) and of the equivalent agri-environmental programme (policy simulations 1P, 2P, and 3P) for different schemes, including public administrative costs.

on the minimum area to be enrolled in the programme by each farm. The existence of a market for alfalfa therefore improves the participation and decreases the cost of the programme.

5. Conclusion

This paper addresses the issue of designing policies for habitat conservation on agricultural land, in the cases which require a non-aggregated spatial distribution of the fields enrolled into an agri-environmental programme. To analyse the design and implementation of an agri-environmental programme aimed at Little Bustard (Tetrax tetrax) conservation in the *Plaine de Niort*, France, we present a spatially explicit mathematical programming farm-based model which accounts for three spatial levels (field, farm and landscape), associated with a relevant spatial pattern index (the Ripley L function). Results show that valuable insights into agri-environmental programme design are gained through a detailed representation of farming system management.

The cost and spatial pattern of the land to come under the conservation programme depend on the participation level of the different farm types. The suitable spatial pattern for the Little Bustard conservation, which requires having Little Bustard-friendly (LBF) managed grassland plots randomly distributed across the area under study, is the most costly one because it tends to require equal participation of all, that is to say "low-cost" as well as "high-cost" farms. Allowing for a higher percentage of the total land required for conservation to be made up of "low-cost" mixed dairy farms, on less fertile soils, decreases the cost of conservation; however, the spatial pattern becomes aggregated and is less suitable for conservation purposes. It is possible to achieve a spatial pattern close to the suitable one but less costly if each farm is required to enrol at least a small area in the LBF AEP. The policy simulations revealed that the various spatial patterns of land under the conservation programme can be obtained through relatively simple uniform contract structures which do not require complete information about, and negotiation with, individual farmers. An effective contract structure, which encourages all farms to enrol at least a small share of their land in the programme, entails a set of two payments whereby one of them is guaranteed up to a certain share of the farm, and the other, much lower one, remunerates all the land enrolled above this limit. Although we see, thanks to the simulations, that the sum of the payments necessary to obtain a given pattern within agri-environmental schemes is always higher than the actual cost of that pattern by at least 62%, the two-payment scheme seems relatively efficient in terms of budgetary expenditure, since this option costs nearly the same as a uniform single payment scheme (which gives rise to an unsuitable, aggregated pattern) but can provide considerably better spatial patterns.

Our modelling approach, which takes simultaneously into account farm behaviour and landscape pattern, contributes to the design of agri-environmental programme when the spatial location of conservation measures matters. However, the research could be extended along several lines. Firstly, we do not account for differences in farm size or farm plot distribution so as to better assess the impact of soil heterogeneity between farms on their participation in the conservation programme and the location of fields that could be enrolled. However, we are aware that these farm characteristics will influence the design of the payment scheme. Hence, further research is needed to extend this work to other situations where either i) only a few large farms operate in the given area or ii) the fields of individual farms are not contiguous but rather dispersed across the landscape, because in those situations the proposed two-payment scheme could easily result in a highly aggregated land pattern. Secondly, in this study we focus on the agri-environmental contract type widely enforced in France and in the E.U., i.e., a uniform subsidy per hectare of land managed according to an environmentally-friendly practice. However, other incentive-based instruments, that have potential to decrease the budgetary expenditures of or improve the spatial allocation of fields enrolled in the conservation programme, do exist. For instance, auction schemes or an agglomeration malus (inspired from the agglomeration bonus used by Parkhurst and Shogren (2007, 2008)) should be further investigated.

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Appendix. Ripley K and L Functions

Interpretation of K(r)

Let A be the area of the zone under study, N the number of observed plots to conserve, and λ the density ($\lambda = N/A$). We have seen in Section 2.2 that $\lambda * K(r)$ can be interpreted as the expected number of further LBF managed grassland plots within a radius r of any arbitrary plot. If conservation plots are randomly distributed within a given radius r, then the expected number of such plots within this radius is equal to $\lambda * \pi r^2$ and $K(r)$ has an expected value of πr^2. The density in the area under study is a given, thus $K(r)$ increases when conservation plots are aggregated at radius r (more neighbours) and decreases when such plots are over-dispersed (less neighbours). In our study, the Little Bustard conservation requires a random distribution of LBF grassland plots, therefore a desirable expected value for $K(r)$ is πr^2.

$\hat{K}(r)$ is an unbiased estimator of $K(r)$. It counts the number of neighbouring conservation plots located within a circle of radius r centred on each conservation plot in the given zone (see Fig. 9), takes the average and divides it by the conservation plot density in the given zone:

$$\hat{K}(r) = \frac{1}{\lambda N} \sum_i \sum_{j \neq i} \left(w_{ir} * I_r \left(d_{i,j} \right) \right)$$

where $d_{i,j}$ is the distance between two LBFmanaged grassland plots, I_r a binary variable equals to 1 if, $d_{i,j} \leq r$ or to 0 otherwise, and w_{ir} an edge-effect correction weighting factor. This weighting factor is inspired by the work of Getis and Franklin (1987) cited in Haase (1995). It is based on the assumption that the density and distribution

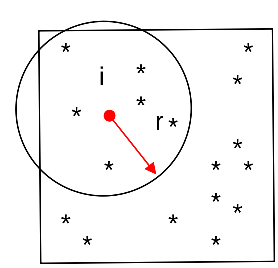

Fig. 9. Illustration of the computation of $\hat{K}(r)$ in a given zone of area A with N plots (*) to conserve.

pattern of neighbouring areas outside and inside the studied zone boundaries are the same:

$$w_{i,r} = \frac{\text{circle area } \left(\pi r^2\right)}{\text{circle area within studied zone boundaries}}$$

Test of the Hypothesis of Complete Spatial Randomness

According to Haase (1995), $\hat{K}(r)$is calculated for the relevant values of r and is tested against the hypothesis of Complete Spatial Randomness (CSR of Diggle, 1983). As mentioned in Section 2.2, we preferentially apply the normalised form of $\hat{K}(r)$, i.e., $\hat{L}(r) = \sqrt{\frac{\hat{K}(r)}{\pi}} - r$, which has an expected value of zero under the null hypothesis of CSR. We use the Monte Carlo method to create a 95% confidence envelope and test $\hat{L}$ against the null hypothesis of CSR. To that end, we simulated N randomly-generated conservation fields following a Poisson distribution on the map of the given area and we calculated the $\hat{L}$ function for the same set of radii as the one used in the scenarios. We repeated the procedure a thousand times and defined the bounds of a 95% confidence envelope for $\hat{L}(r)$.

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